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MOISTURE FLUX
THROUGH THE
BILLINGS LANDFILL

# Moisture Flux through the Billings Landfill

Report No. 176

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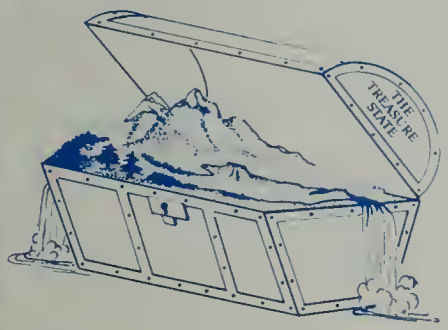


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**Moisture Flux through the Billings Landfill**

Report No. 176

by

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Final Technical Report Submitted to
The Montana Water Resources Center
Montana State University
Bozeman, Montana

1991

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COMPLETION REPORT

Project No. 03 MONT

# MOISTURE FLUX THROUGH THE BILLINGS LANDFILL

MUJWRRC Report No. 176

by

Jon Reiten
Montana Bureau of Mines and Geology
Billings, Montana 59101

Montana University Joint Water Resources Research Center
Montana State University
Bozeman, Montana 59715

July 1992

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Plate

1 Billings Landfill.....in back pocket

## INTRODUCTION

The migration of leachate from municipal landfills into the surrounding ground water is a potential threat to the quality of both developed and undeveloped water resources. Public concern regarding the threat to ground water supplies from leaking landfills has led to recent legislation requiring extensive ground-water monitoring associated with all landfills. In addition, the new landfill rules require that leachate migration at all new municipal landfills be prevented by leachate collection systems.

Stemmed by the new rules and public concerns the city of Billings has hired consultants to investigate the hydrologic conditions at the city landfill. In addition, the city granted permission and access for the MBMG to assess moisture flux through the Billings landfill.

Moisture flux through landfills is typically determined by using computer models such as the HELP model (Hydrologic Assessment of Landfill Performance). Most ground-water models currently in use for assessing moisture flux were developed in sub-humid to humid climates. These models often do not adequately deal with changing soil moisture gradients. The reversal of soil moisture gradients could result in soil moisture actually flowing towards the surface, removing it from the reservoir of potential leachate. Models such as the HELP model may not be adequate to determine the moisture flux through landfills in semiarid climates due to the dominance of climatic conditions not found where these models were developed. In spite of these potential limitations, the HELP model was used to estimate the volume of leachate produced at the Billings Landfill during 1990 and 1991.

The SWIM model (a model for Soil Water Infiltration and Movement) simulates water infiltration and movement through soils (Ross, 1990). This model assumes: horizontally uniform soil conditions, flow is described by the Richards equation, and soil hydrologic characteristics can be described by simple functions. During a simulation, water is added by precipitation; and is removed by runoff, drainage, and evapotranspiration (Richards, 1931). The SWIM model was used to estimate the volume of moisture moving through the landfill cover.

## PURPOSE

Accurately assessing the moisture flux and leachate generation potential of a landfill are important elements in evaluating both existing and future landfill sites. At a landfill site with an existing leachate problem, modelling is one tool that is often used in assessing the migration of leachate through the waste and the unsaturated zone beyond the boundaries of the landfill. Predicting contaminant migration in the saturated zone will also require an accurate determination of the rate of leachate loading to the ground-water system. Landfill modelling is also an integral part of landfill siting and design. Landfill modelling can be used to estimate the potential leachate volume at the site. In addition, during the landfill design phase, the results of modelling can be used to assess the attenuative capacity of the hydrogeologic system beneath the landfill.

By evaluating the hydrologic system at the Billings landfill and monitoring moisture conditions in both the unsaturated zone and

the saturated zone predictions can be developed for evaluating leachate generation models typically used in a landfill environment.

## SETTING

The Billings Landfill is located on the south side of the Yellowstone River valley in Township 1 South, Range 26 East, Sections 29 and 30, about 2 miles south of the city of Billings (Figure 1). The landfill is underlain by gray shale of the Colorado Group and colluvial deposits composed largely of reworked shale. A generalized diagram of the landfill is shown in Figure 2. Major components of the landfill include: 1. shale base, 2. waste, 3. cover layer. The shale base is relatively impermeable; effectively forming a barrier to water movement. The waste layer averages 8-10 feet thick and consists of compacted garbage. The cover layer is artificial fill consisting of shale and clay excavated from nearby outcrops. In permanent or semi-permanent landfill covers, a thin 6-12 inch layer of humic material is emplaced at the surface to enhance growth of vegetation. The term lift refers to a layer of waste overlain by a cover layer.

Most of the landfill occupies a small drainage basin that was incised into the valley wall. Sections of the landfill located outside of this drainage basin were not investigated. The land surface of the landfill slopes to the north from about 3550 feet above sea level at the south end to about 3200 feet above sea level at the north end. The Yellowstone River flows within about 1/2 mile of the landfill at an elevation of about 3,180 feet above sea level.

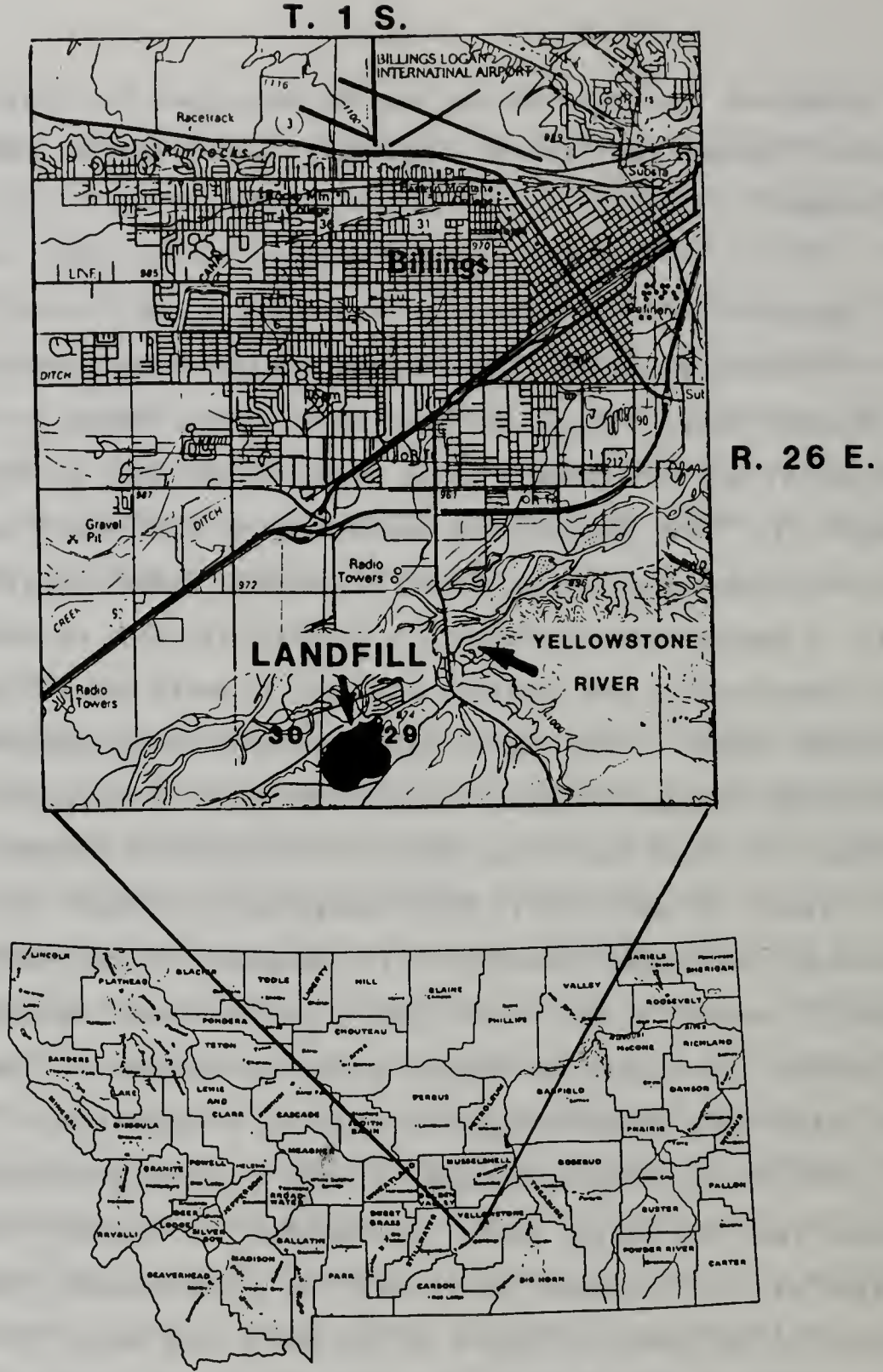


Figure 1. Location of the Billings Landfill.

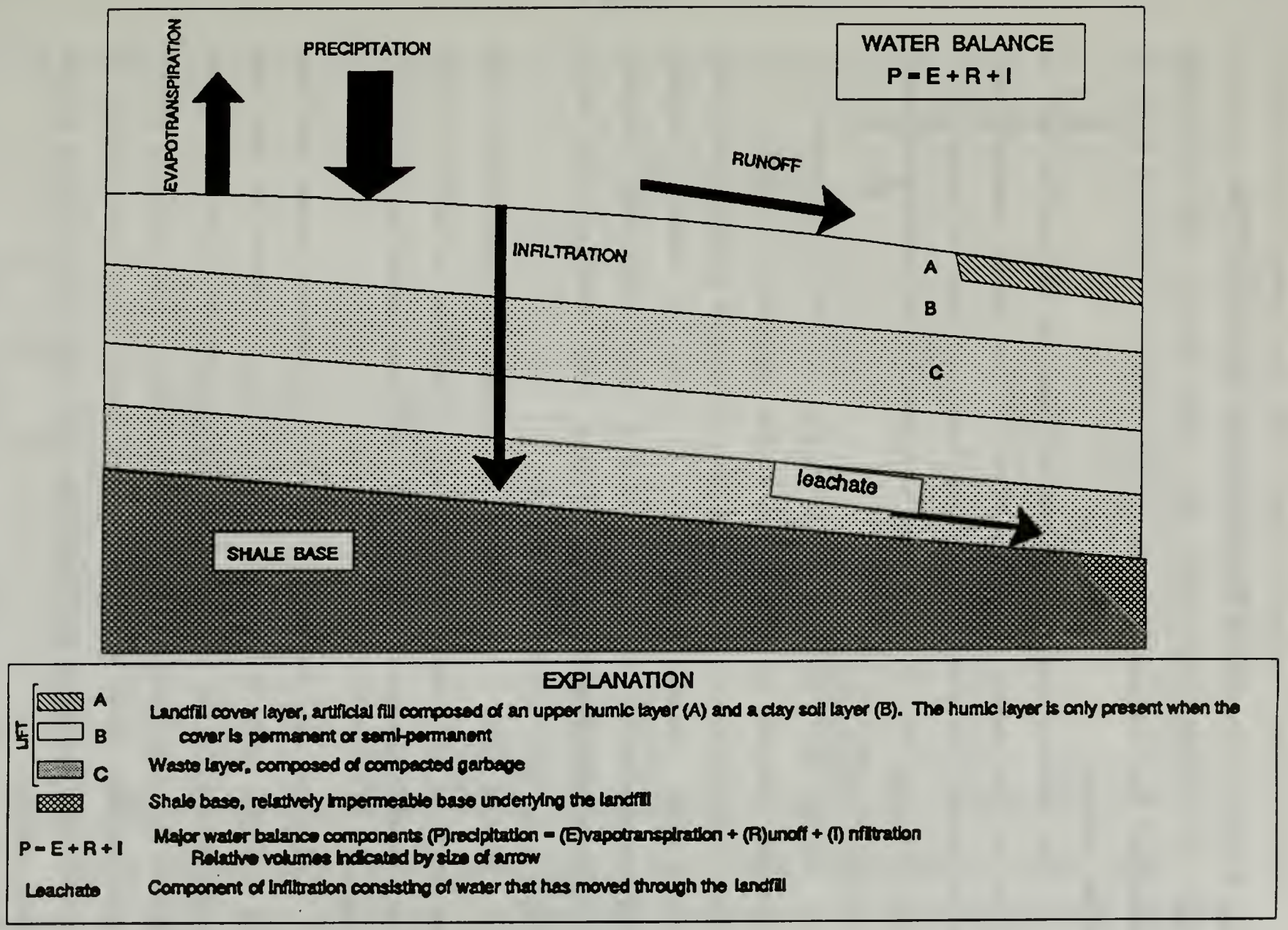
EVAPOTRANSPIRATION
PRECIPITATION
WATER BALANCE
P = E + R + I
RUNOFF
INFILTRATION
A
B
C
leachate
SHALE BASE
EXPLANATION
LFT
A
B
C
Landfill cover layer, artificial fill composed of an upper humic layer (A) and a clay soil layer (B). The humic layer is only present when the cover is permanent or semi-permanent
Waste layer, composed of compacted garbage
Shale base, relatively impermeable base underlying the landfill
P = E + R + I
Major water balance components (P)recipitation = (E)vapotranspiration + (R)unoff + (I) nfiltration
Relative volumes indicated by size of arrow
Leachate
Component of infiltration consisting of water that has moved through the landfill

Figure 2. Generalized diagram of major components of the Billings landfill and the major components of the water balance.

## CLIMATE

Billings has a semiarid climate with warm summers cold winters and moderate amounts of precipitation. Because of the location near the borderline between the Great Plains and the Rocky Mountains the climate is influenced by characteristics of both of these regions.

The average annual precipitation based on the period 1961 to 1990 is 14.3 inches. About a third of the annual precipitation falls during the months of May and June. Winters are generally dry with less than 20 percent of the annual precipitation expected between November and February.

Winter is cold but temperatures are often moderated by extended periods of mild temperatures typically brought on by strong southwesterly (chinook) winds. Spring is usually cloudy and cool with frequent episodes of rain or snow. Summer characteristically has warm days and cool nights with frequent afternoon thunderstorms. Fall months cycle between cool moist conditions and warm dry conditions.

During 1990 a total of 11.27 inches of precipitation was recorded at Billings. Spring precipitation was slightly greater than normal; but drier than normal conditions prevailed during the summer.

Climatic conditions were significantly wetter during 1991 than is typical (Figure 3). A total of 20.73 inches of rain was recorded during the year. Most of the precipitation fell during the spring and early summer although the fall was also slightly wetter than normal. June was the wettest month with 5.62 inches of precipitation. April and September were also significantly wetter than normal.

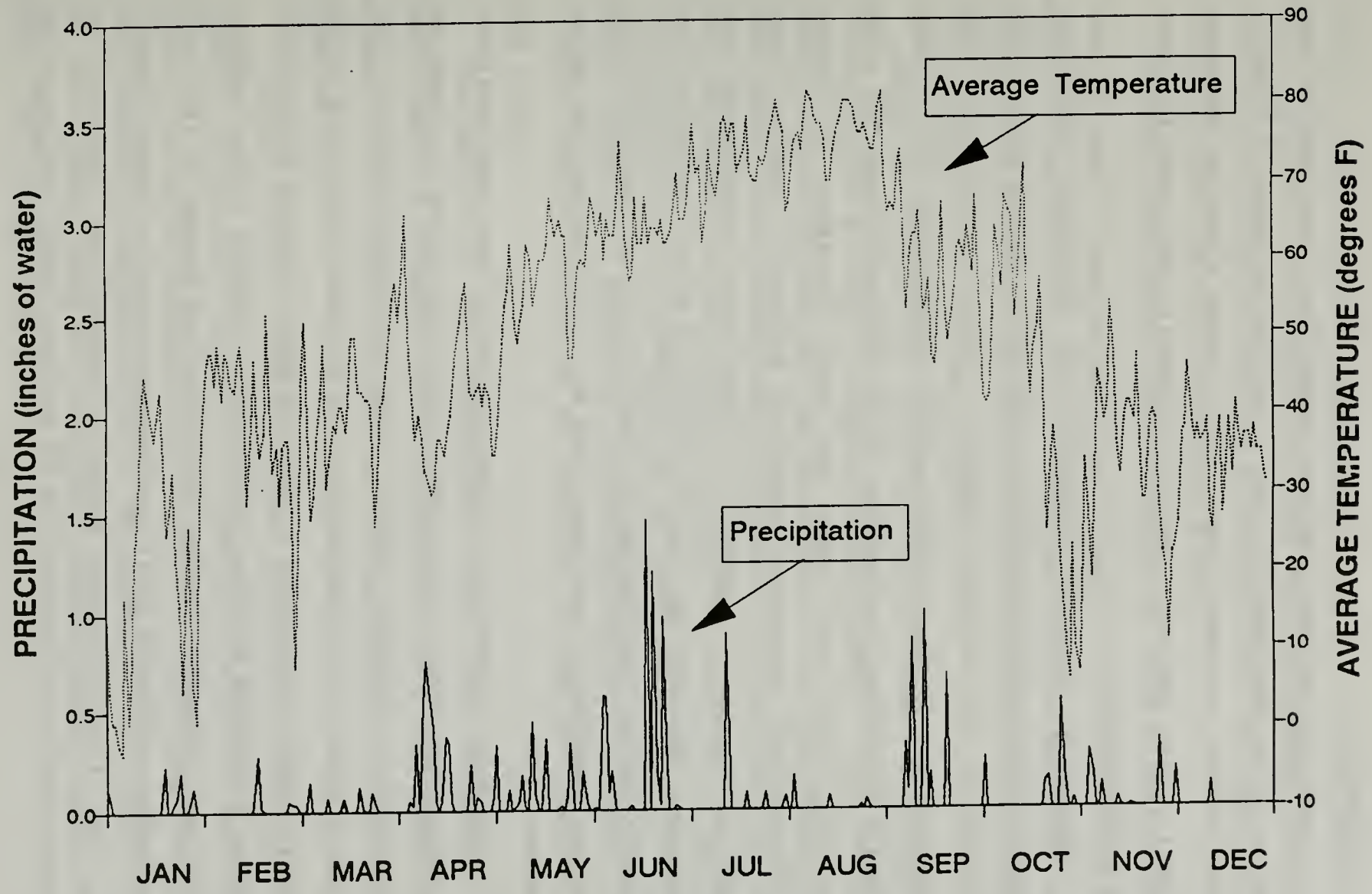


Figure 3. Daily precipitation and average daily temperature for 1991 based on data from the NOAA station at the Billings airport.

METHODS

Topography and other physical properties of the landfill were used to divide the landfill into 5 sections as shown in Plate 1. These sections are named from higher to lower elevation the Upper Landfill, Upper Landfill Slope, Main Landfill, Main Landfill Slope, and Lower Coulee.

Monitoring devices designed for measuring hydrologic properties of both the unsaturated zone and the saturated zone were installed in the Billings landfill. Three monitor wells were installed in the Lower Coulee section, downgradient of the Main Landfill to monitor fluctuations in the saturated zone. The wells are all about 30-ft deep and were installed in shaley colluvium/shale underlying landfilled material. Logs of these wells are located in Appendix A. Water level fluctuations were measured to determine the impact of recharge from precipitation and possible lateral flow through the landfill. Water level monitoring has been essentially continuous from May, 1991 through the end of December 1991.

Hydrologic conditions of the unsaturated zone were monitored by permeameter tests, soil suction data from nested tensiometers and relative moisture content using a Campbell-Pacific soil moisture probe. The uppermost part of the unsaturated zone is the landfill cover, consisting of clay and shale designed to cover the garbage and retard moisture infiltration. Studies of the landfill cover were conducted during the spring and summer of 1991 with monitoring continuing until late November when the ground froze.

The field saturated hydraulic conductivity (Kfs) of the landfill cover was measured at 32 sampling sites throughout the

landfill using a Guelph permeameter (Table 1). These sampling sites represented 21 different locations with measurements taken at different stratigraphic intervals at several sites. The location of the measurement sites are plotted on Plate 1.

Eleven tensiometers were installed at four sites in the landfill cover. These were designed to measure soil suction and to monitor fluctuations in the soil suction. Both the magnitude and direction of hydraulic gradients in the unsaturated zone can be determined based on this information.

Moisture distribution within the landfill cover was monitored using a neutron probe at 5 different sites (Plate 1). The neutron probe measures the hydrogen ion concentration within a relatively small radius surrounding the access tube. The magnitude of the response commonly correlates directly with the water content of the soil. Changes in the response at a specific horizon commonly relates directly to changes in moisture conditions in the soil. As a result wetting fronts can be monitored as they move through a soil horizon.

Monitoring of the unsaturated zone was conducted on approximately a bi-weekly basis throughout most of the summer; the schedule was dictated largely on the availability of the soil moisture probe.

Computer models including HELP (Hydrologic Evaluation of Landfill Performance) and SWIM (a simulation model for Soil and Water Infiltration Movement) were tested to assess the moisture flux through the Billings Landfill. The models were driven by 1990 to 1991 climatic data and hydrologic data collected during 1991 (NOAA, 1990, NOAA, 1991).

TABLE 1. SUMMARY OF BILLINGS LANDFILL PERMEAMETER TESTS

| SITE ID | SOIL TYPE | HYDR. COND. FIELD SAT. cm/sec | MATRIC FLUX POTENTIAL cm/sec2 | DENSITY OF VEGETATION | TOTAL DEPTH ft | LANDFILL SECTION |
|---|---|---|---|---|---|---|
| GP-01 | SILTY, SANDY, CLAY | 0.00004000 | 0.00360000 | MODERATE | 0.67 | LOWER COULEE |
| GP-02 | SANDY LOAM | 0.00015000 | 0.00070000 | MODERATE | 0.67 | LOWER COULEE |
| GP-03 | SILTY CLAY | 0.00000230 | 0.00010000 | MODERATE | 0.83 | LOWER COULEE |
| GP-04A | SILTY, SANDY CLAY | 0.00008200 | 0.00027000 | MODERATE | 0.67 | LOWER COULEE |
| GP-04B | SILTY, SANDY CLAY | 0.00087000 | -0.00465000 | MODERATE | 1.60 | LOWER COULEE |
| GP-05A | SILTY CLAY | 0.00000025 | 0.00001000 | MODERATE | 0.75 | LOWER COULEE |
| GP-05B | SILTY CLAY | 0.00003100 | -0.00015000 | MODERATE | 1.50 | LOWER COULEE |
| GP-06A | SILTY CLAY | 0.00120000 | -0.00677000 | THIN | 0.83 | MAIN LANDFILL SLOPE |
| GP-06B | SILTY CLAY, GARBAGE | -0.01119000 | 0.24000000 | THIN | 1.50 | MAIN LANDFILL SLOPE |
| GP-07 | CLAYEY, SILT, SHALE, PEBBLES | 0.00031600 | 0.00058200 | THIN | 0.83 | MAIN LANDFILL SLOPE |
| GP-08A | SANDY, SILTY, CLAY | 0.00000300 | 0.00007900 | THIN | 0.75 | MAIN LANDFILL SLOPE |
| GP-08B | SILTY, SANDY, CLAY, GARB., PEBBS | 0.00055300 | -0.00263000 | THIN | 1.25 | MAIN LANDFILL SLOPE |
| GP-09A | CLAYEY SILT | 0.00638000 | 0.00500000 | MODERATE | 0.50 | UPPER LANDFILL |
| GP-09B | SILTY, CLAYEY, SALT STRINGERS | 0.00180000 | -0.00820000 | MODERATE | 0.83 | UPPER LANDFILL |
| GP-09C | GARBAGE, CLAY | 0.00064300 | -0.05200000 | MODERATE | 1.67 | UPPER LANDFILL |
| GP-10A | SANDY, CLAYEY SILT | 0.00056700 | -0.00024300 | MODERATE | 1.00 | UPPER LANDFILL |
| GP-11A | CLAYEY, SILT, HARD SHALE | 0.00653000 | -0.02410000 | MODERATE | 0.83 | UPPER LANDFILL |
| GP-12A | CLAYEY SILT LAYERS | 0.00003700 | 0.00016000 | MODERATE | 0.83 | UPPER LANDFILL |
| GP-12B | SILTY CLAY, GARBAGE | 0.00021300 | -0.00096800 | MODERATE | 1.67 | UPPER LANDFILL |
| GP-13A | SILTY CLAY | 0.00020000 | -0.00068000 | MODERATE | 0.83 | UPPER LANDFILL |
| GP-13B | SILTY CLAY, GARBAGE | -0.00000400 | 0.00026200 | MODERATE | 1.50 | UPPER LANDFILL |
| GP-14A | CLAYEY SILT, GARBAGE | 0.00002300 | 0.00001100 | MODERATE | 0.83 | UPPER LANDFILL |
| GP-14B | SILTY SHALE, HARD | 0.00008460 | -0.00028100 | MODERATE | 1.58 | UPPER LANDFILL |
| GP-15 | SILTY CLAY | 0.00000197 | 0.00008300 | BARE | 0.58 | MAIN LANDFILL |
| GP-16 | SILTY CLAY, GARBAGE | -0.00001370 | 0.00023200 | BARE | 0.83 | MAIN LANDFILL |
| GP-17 | SILTY CLAY | -0.00000963 | 0.00015900 | BARE | 0.75 | MAIN LANDFILL |
| GP-18 | SILTY CLAY, BENTONITE | 0.00002520 | 0.00003620 | BARE | 0.75 | MAIN LANDFILL |
| GP-19A | SILTY CLAY | 0.00007960 | -0.00041300 | BARE | 0.75 | MAIN LANDFILL |
| GP-19B | SILTY CLAY, SHALE, PEBBLES | 0.00001640 | 0.00011300 | BARE | 1.50 | MAIN LANDFILL |
| GP-20 | SILTY CLAY, GARBAGE | 0.00017900 | 0.00009660 | BARE | 0.83 | MAIN LANDFILL |
| GP-21A | CLAYEY SILTY | 0.18000000 | -0.98000000 | MODERATE | 0.67 | UPPER LANDFILL |
| GP-21B | CLAYEY SILT, SHALE, PEB. & GRVL | 0.00017500 | 0.00049400 | MODERATE | 1.50 | UPPER LANDFILL |

## PHYSICAL AND HYDROLOGIC CHARACTERISTICS OF THE BILLINGS LANDFILL

The Billings landfill covers over 80 acres within a drainage basin covering about 140 acres. Physical criteria used to divide the landfill into 5 different sections includes: location within the landfill, topography, slope of the land surface, physical properties of the cover material, age of the waste, and density of the vegetative cover. The five sections making up the landfill are: 1. the Upper Landfill (UL), 2. Upper Landfill Slope (ULS), 3. Main Landfill (ML), 4. Main Landfill Slope (MLS), and 5. Lower Coulee (LC) (Plate 1). The lithologic description of the landfill cover is based on observations during soil borings drilled for conducting permeameter tests, neutron access tube installation, and tensiometer installation. Logs of soil borings are listed in Appendix B.

The landfill operation originally progressed by filling in natural gullies with garbage. There currently is significantly more earth moving involved; ridges are excavated both for cover material and to fill in swales. The result is the development of large flat areas where lifts of garbage can be systematically emplaced allowing for more efficient use of space, time and manpower. Each lift of garbage is about 10- to 12-ft thick. The garbage is compacted and covered daily with a minimum of six inches of dirt. A temporary cover of 1- to 2-ft of dirt is used to cap garbage when it is left for several days. The design for the final cover is a permanent cap overlying the garbage consisting of 3-ft of compacted dirt with a vegetative layer at the surface.

Both the unsaturated zone and the saturated zone were monitored to characterize the significant hydrologic parameters of

the landfill. Results of permeameter tests produced field saturated hydraulic conductivities and matric flux potentials for the landfill cover in 4 of the 5 landfill sections. About one-half of the tests yielded negative values, implying soil heterogeneity (Table 1). When a negative Kfs or matric flux potential is calculated using a Guelph permeameter, it indicates a hydrologic discontinuity in the horizon tested (Soil Moisture Equipment Corp., 1986). These discontinuities may be caused by rodent holes, root holes, fractures, swelling clays, and other anomalies. When a permeameter test resulted in either a negative Kfs or matric flux potential, neither of the values were used for characterizing the landfill cover.

Tensiometers measured the matric potential or soil suction that soil moisture is under at a specific depth (Hillel, 1980). Nests of tensiometers in several sections of the landfill provided vertical gradients of the matric potential, indicating the potential soil moisture flux. Both upward and downward gradients were observed during the period of monitoring.

Neutron probe readings relate directly to the volume of moisture in a soil by depth (Campbell Pacific Nuclear Corp., 1980). Periodic profiles of the landfill cover in several different sections of the landfill identified changes in the relative volume of soil moisture caused by precipitation and evapotranspiration.

Water levels in monitoring wells fluctuated in response to recharge and ground-water flow through the colluvium and weathered shale underlying the Lower Coulee section of the landfill. Logs and construction details of monitor wells are listed in Appendix A.

Hydrologic processes impacting the water balance of the landfill includes: precipitation, temperature, surface runoff, evapotranspiration, and infiltration. The hydrologic characteristics of the cover material, garbage, and the basal shale; combined with the hydrologic processes, climatic conditions, vegetative cover, and surface slope impact the total water balance of the landfill.

UPPER LANDFILL

The Upper Landfill (UL) covers about 23.6 acres (1,027,200 square feet) near the drainage divide at the south edge of the landfill. The average slope of this surface is about 0.031ft/ft. Garbage buried in the UL ranges from 0- to 80-ft thick and averages about 60-ft thick (personal communication, Randy Crable). Soil borings penetrated about 30 inches into the cover material. Consisting largely of brownish gray to gray silty clay, the cover ranges from 1- to 3-ft thick. The cover is composed of an upper 3- to 10-inch layer of very organic rich loam overlying a lower 12- to 24-inch layer of brownish gray silty clay. Most of the UL surface is covered by a moderately thick growth of grass, although several parts of this surface are bare or only covered by sparse vegetation.

One permeameter test in the UL cover measured a Kfs in the upper loam of 0.00638 cm/sec. Permeameter tests in the silty clay layer underlying the loam measured Kfs ranging from 0.000023 cm/sec to 0.000175 cm/sec. Based on 3 tests, the average Kfs for the silty clay part of the UL cover was 0.000783 cm/sec.

Soil moisture conditions were monitored at SM-01 and SM-02 in the UL cover (Plate 1). The matric potential gradients are summarized in figures 4 and 5. Figure 4 indicates changes in the matric potential gradients at SM-01 during 1991; based on the deep interval T1-T2 (from 1.33- to 0.91-ft below ground) and the shallow interval T2-T3 (from 0.91- to 0.51-ft below ground). Descending moisture flux could potentially produce landfill leachate by gravity drainage; while ascending moisture flux could remove water from the landfill by evapotranspiration. Initially at SM-01, upward gradients in the shallow interval and downward gradients in the deep interval appear to indicate the potential for both upward and downward movement of moisture. Summer rainstorms produced descending matric potential gradients for both intervals. This is best shown by the gradients for late July, early August and mid September. Hot and dry conditions in August probably increased evapotranspiration producing the ascending matric potential gradients. Upward gradients for the deep interval are also indicated in late May and early September. It is likely that if the information had been available; upward gradients would also have been observed in the shallow interval. In many cases, data was lost from one or more tensiometers when the reservoirs ran out of water prior to routine measurement. Gradients cannot be determined when one tensiometer out of a nested pair has failed.

Figure 5 indicates changes in the matric potential gradients at SM-02 during 1991, based on the interval between tensiometers T4-T5 (from 0.58- to 1.0-ft below ground). The gradients at SM-02 were similar to the gradients in the shallow interval at SM-01; implying similar responses to precipitation and evapotranspiration at these sites.

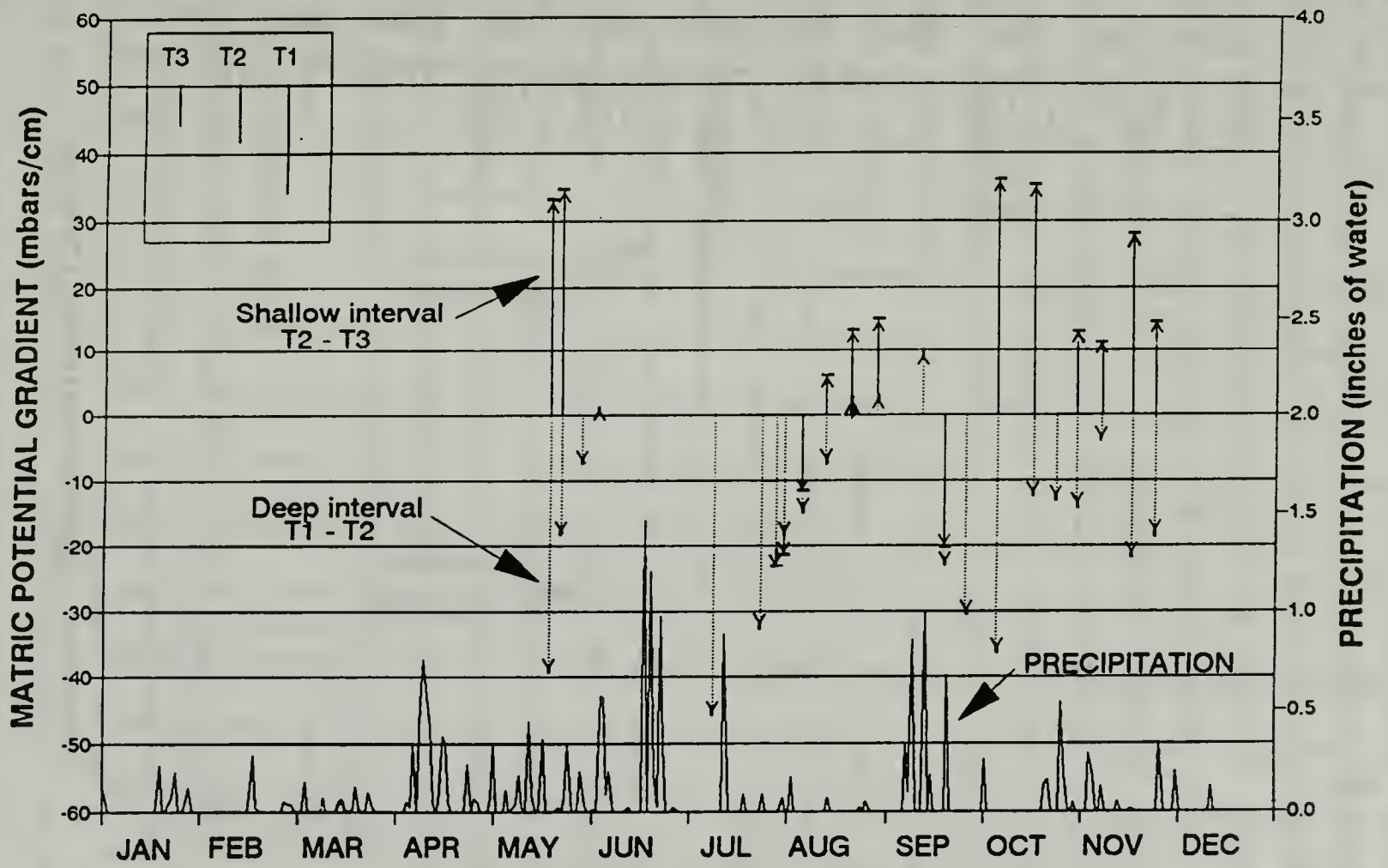


Figure 4. Fluctuations of the matric suction gradients at SM-01 during 1991. Upward gradients are indicated by values greater than zero and downward gradients are indicated by values less than zero. The deep tensiometer interval is based on suction data from T1 set at 1.33 feet below land surface and T2 set at 0.91 feet below land surface. The shallow tensiometer interval is based on suction data from T2 set at 0.91 feet below land surface and T3 set at 0.51 feet below land surface.

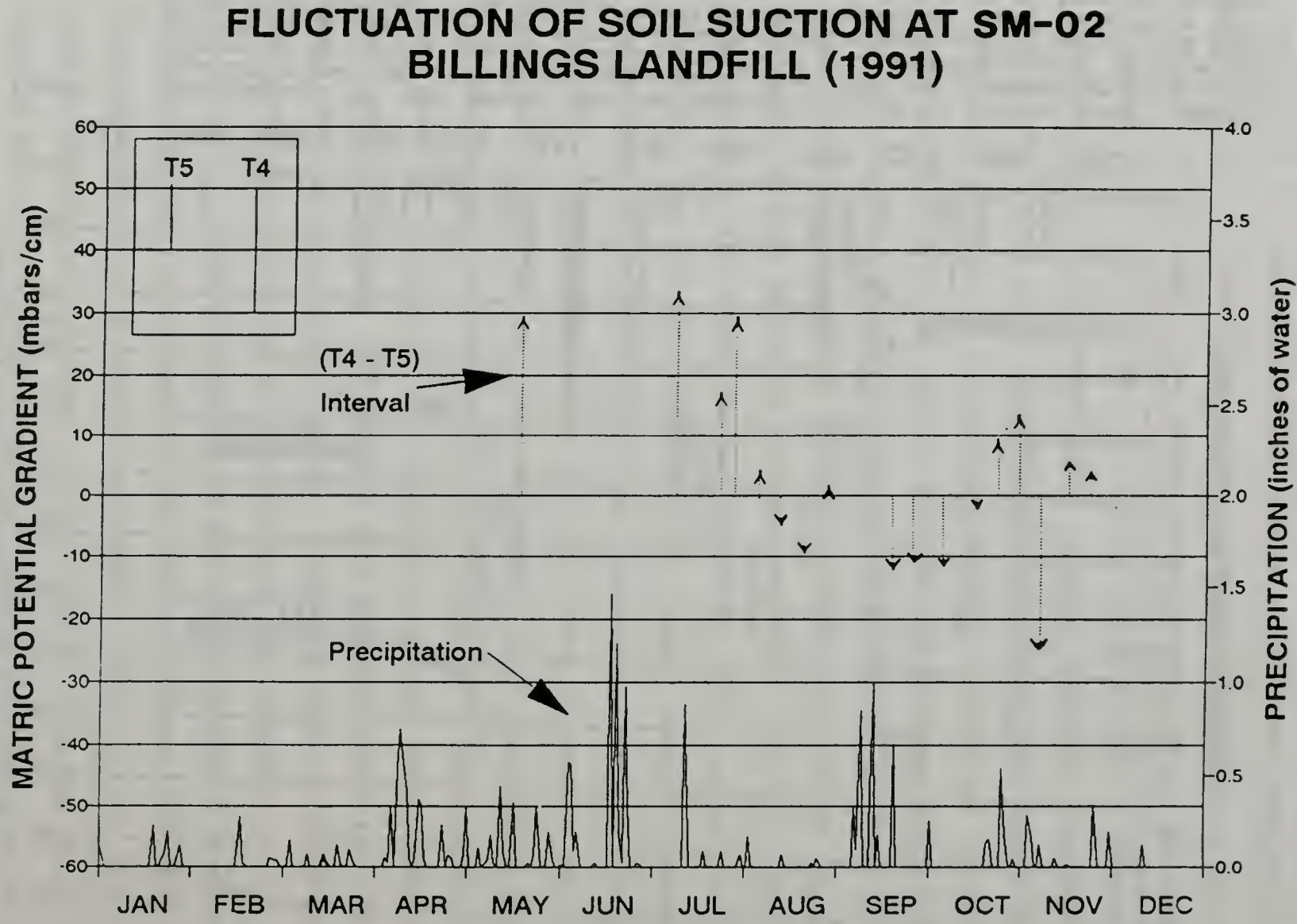


Figure 5. Fluctuations of the matric suction gradients at SM-02 during 1991. Upward gradients are indicated by values greater than zero and downward gradients are indicated by values less than zero. The tensiometer interval is based on soil suction data from T4 set at 1.0 feet below land surface and T5 set at 0.91 feet below land surface.

Fluctuating moisture conditions were also recorded by the soil-moisture probe at SM-01 and SM-02 in neutron access tubes #1 and #2 (Figures 6 and 7). The volume of moisture measured in the soil horizon tested declined from May 20 to June 4 at both sites. Increased evapotranspiration as plants grew and temperatures rose removed much of the water from the soil. In addition, infiltration of May rainfall through the cover reduced the volume of moisture in the soil horizon tested. Significant wetting fronts were identified at both access tubes on July 10 and July 30,in response to summer rainfall. What appears to be the downward migration of these wetting fronts is apparent on figure 5. Higher moisture content between the 1.0-1.3 ft interval on July 25, between the 1.3-1.5 ft interval on July 30, and at the 1.5-ft level on August 1 is probably the result of downward migration of the July 10 wetting front. A similar movement of the July 30 wetting front appears at the 0.8-1.2 ft level on August 1.

Both infiltration (indicated by downward matric potential gradients) and evapotranspiration (indicated by upward matric potential gradients) dominated the hydrologic processes in the UL cover. Although moisture probably infiltrates throughout the year, significant infiltration occurred during July as indicated by both matric potential gradients and wetting fronts during July.

UPPER LANDFILL SLOPE

The Upper Landfill Slope (ULS) covers about 11 acres (478,800 square feet)immediately north of the UL. The slope of this surface is relatively steep at about .18 ft/ft towards the north. Garbage buried below this surface ranges from 10- to 150-ft and averages about 80-ft thick. No soil borings penetrated this surface; but

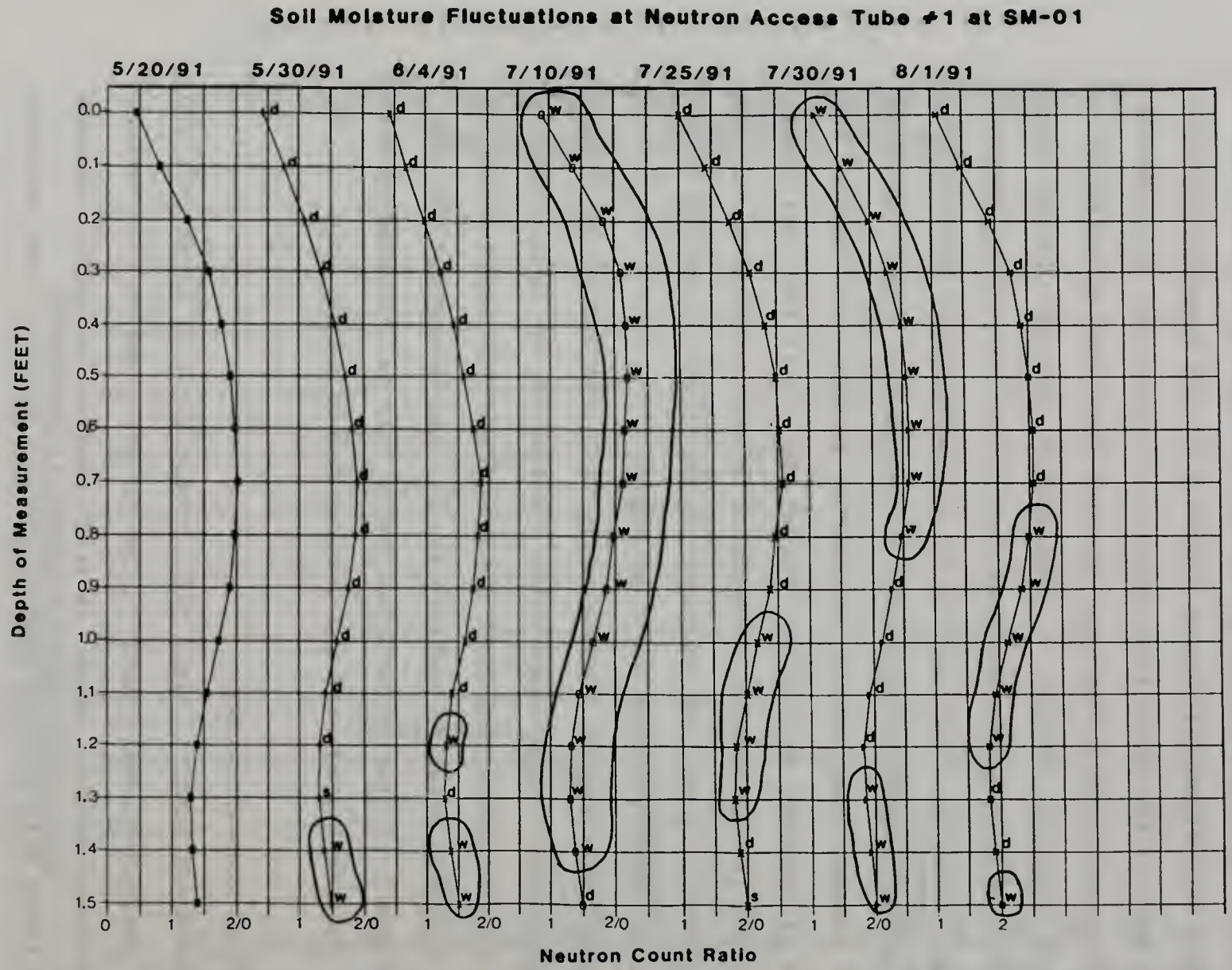


Figure 6. Soil moisture fluctuations at neutron access tube #1 located in the upper landfill section of the Billings Landfill at site SM-01. The fluctuations were determined by changes in the neutron count ratio at specific depths through time. A "w" indicates wetter conditions, a "d" indicates drier conditions and an "s" indicates the same moisture conditions as were measured at the same depth interval during the previous measurement.

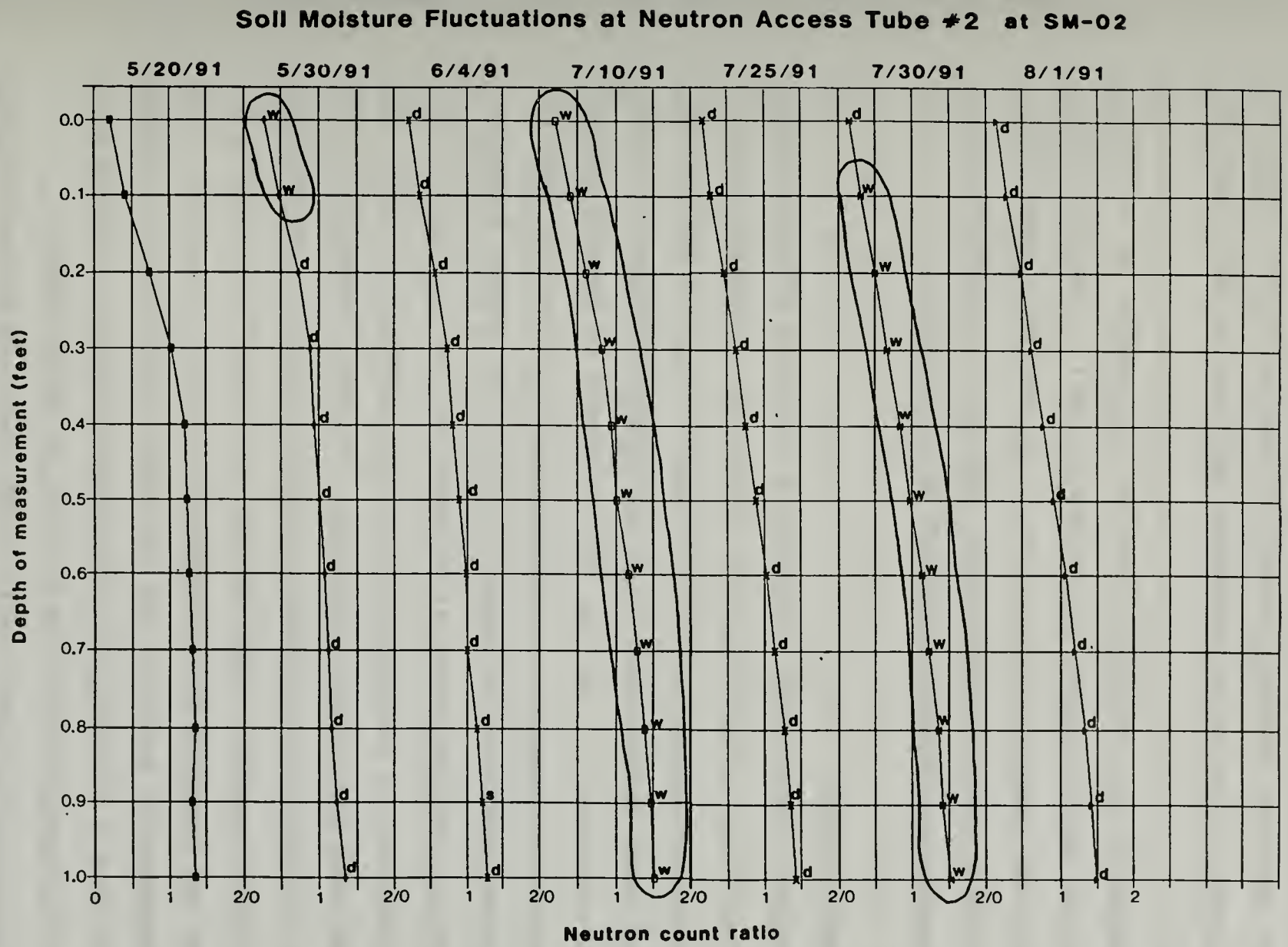


Figure 7. Soil moisture fluctuations at neutron access tube #2 located in the upper landfill section of the Billings Landfill at site SM-02. The fluctuations were determined by changes in the neutron count ratio at specific depths through time. A "w" indicates wetter conditions, a "d" indicates drier conditions and an "s" indicates the same moisture conditions as were measured at the same depth interval during the previous measurement.

based on the surficial material and nearby borings into the main landfill the cover probably consists of gray silty clay. Most of this surface is barren of vegetation with only a few clumps of grass.

The hydrologic characteristics for this section are probably similar to those measured in the Main Landfill (see following section). One significant difference is the relatively steep slope of the ULS, which significantly reduces the potential for infiltration and increases the potential for runoff.

MAIN LANDFILL

The Main Landfill (ML) covers about 21.9 acres (954,200 square feet) below and immediately north of the ULS. The slope of this surface is relatively flat dipping about 0.034 ft/ft towards the north. A small section of the ML is isolated from the main section and is surrounded by the ULS. The thickness of garbage buried beneath the ML ranges from a thin featheredge on the east side to over 200-ft thick near the center of the ML. The average thickness of garbage underlying the ML is estimated at 100 ft. Soil borings penetrated up to 3 feet of the ML surface. Consisting largely of grayish brown to dark gray silty clay, the cover ranges from about 1- to 3-ft thick. This surface is completely barren of vegetation. The ML is the major active section of the landfill. Lifts of garbage are compacted and covered daily.

Permeameter tests in the ML cover identified Kfs values ranging from 0.00000197 to 0.000179 cm/sec (Table 1). Based on 5 tests the average Kfs for the ML cover is .00005 cm/sec.

Soil moisture conditions in the ML cover were monitored at SM-03. The magnitude and direction that matric potential gradients

fluctuated during 1991 are depicted in Figure 8. The deep interval was based on the observed gradient between T6 (2.42 ft below ground) and T7 (1.42 ft below ground); while the shallow interval was based on the observed gradient between T7 and T8 (0.83 ft below ground). All measurements of the shallow interval indicated downward gradients. In contrast, the deep interval indicated upward gradients during May and early June; changing to downward gradients during July and early August. The magnitude of the deep interval gradient was relatively small for all of the measurements; indicating relatively stable moisture conditions for the deep interval. The larger magnitude of the shallow interval indicates greater matric potential differences across this zone. The converging gradients during May and early June probably are the result of very dynamic climatic and soil hydrologic conditions caused by numerous periods of rain interspersed with drying conditions.

Changes in the volume of moisture in the ML cover are depicted in Figure 9 based on soil moisture measurements from neutron access tube #3. The upper 0.5 ft of the soil horizon was generally drier than preceding measurements with the exception of increases in moisture content detected on May 30 and July 30. Several poorly defined zones of increased moisture content were common; with only a few indicating significant wetting fronts moving through the cover. The most significant wetting front identified in the ML was detected on July 30; unfortunately this site had to be abandoned after August 1 because of landfill progression.

The hydrologic process dominating the ML appears to be downward infiltration of moisture. Matric potential gradients are typically down with little evidence of reversals.

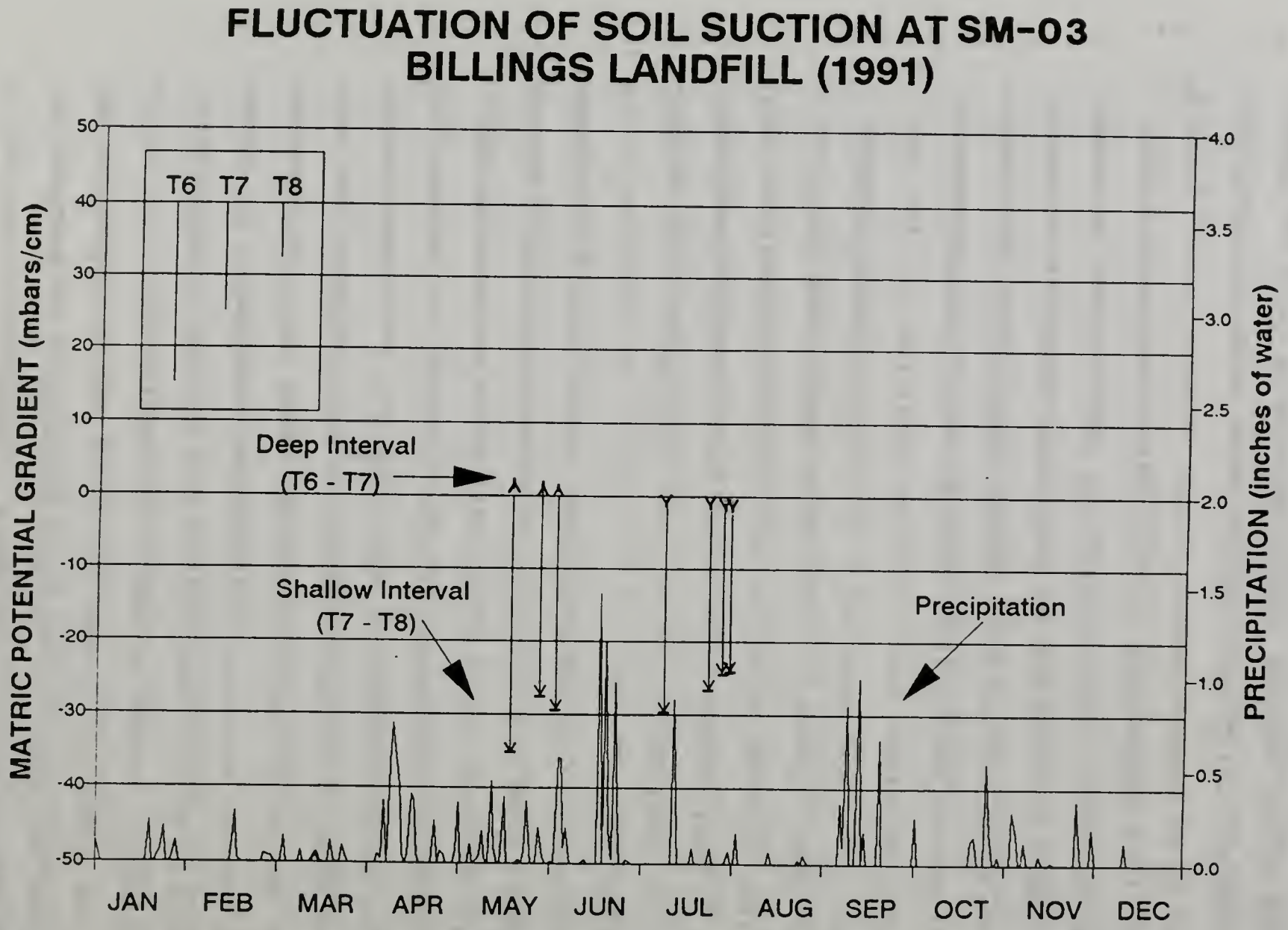


Figure 8. Fluctuations of the matric suction gradients at SM-03 during 1991. Upward gradients are indicated by values greater than zero and downward gradients are indicated by values less than zero. The tensiometer interval is based on soil suction data from T6 set at 2.42 feet below land surface, T7 set at 1.42 feet below land surface and T8 set at 0.83 feet below land surface.

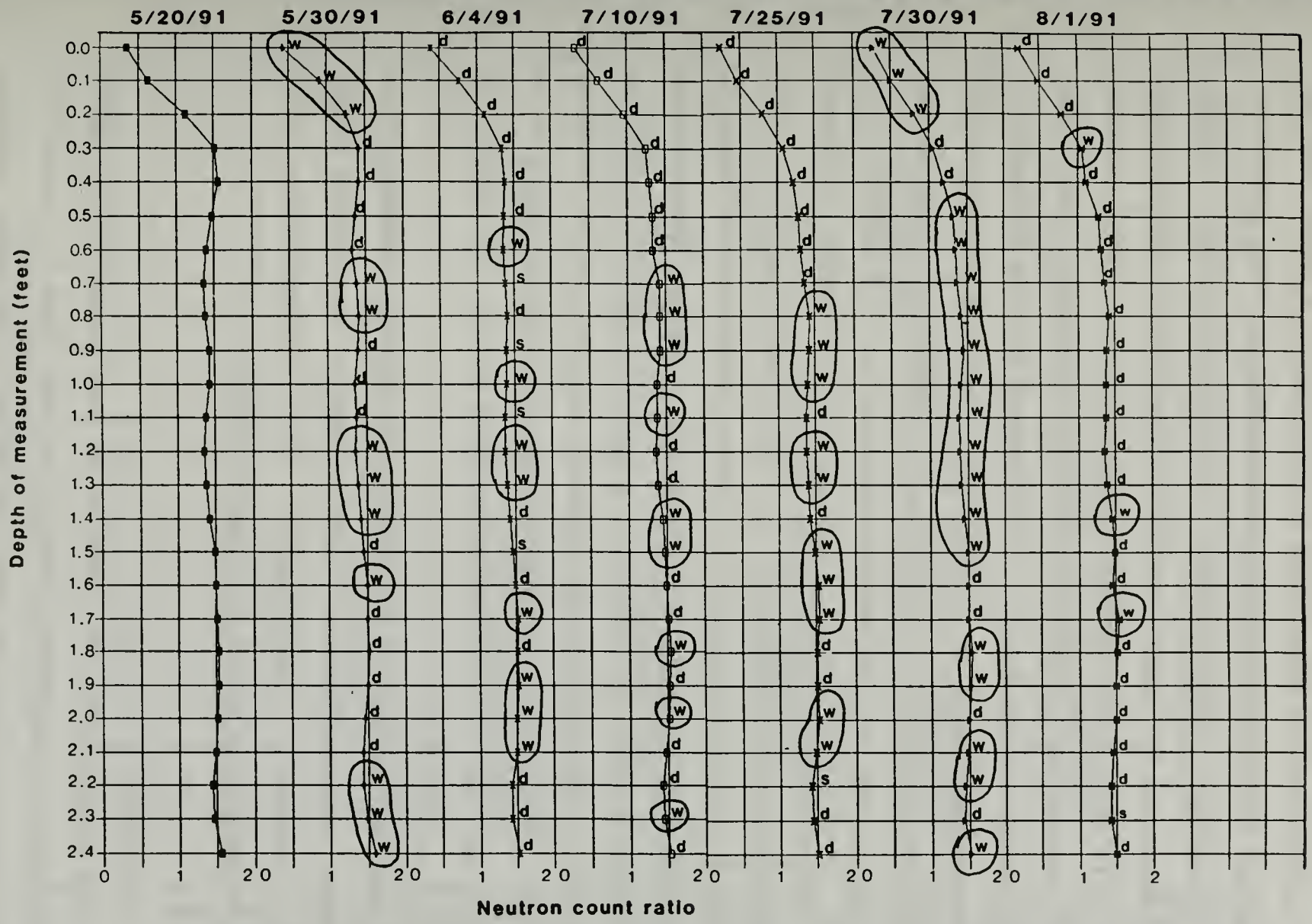


Figure 9. Soil moisture fluctuations at neutron access tube #3 located in the main landfill section of the Billings Landfill at site SM-03. The fluctuations were determined by changes in the neutron count ratio at specific depths through time. A "w" indicates wetter conditions, a "d" indicates drier conditions and an "s" indicates the same moisture conditions as were measured at the same depth interval during the previous measurement.

MAIN LANDFILL SLOPE

The Main Landfill Slope (MLS) covers about 13.5 acres (589,600 square feet) below and immediately north of the ML. This surface is relatively steeply sloping at about .19 ft/ft to the north. Garbage buried below the MLS ranges from 0- to 200-ft thick and averages about 80 ft thick. Soil borings penetrated up to 3-ft of the MLS cover. Consisting largely of dark gray silty clay, the cover ranges from 1- to 3-ft thick, and is covered by thin vegetation.

Permeameter tests in the MLS cover resulted in Kfs values ranging from 0.000003 to 0.000316 cm/sec (Table 1). Based on two tests the average Kfs for the MLS cover was 0.00016 cm/sec.

Soil moisture conditions were measured in the MLS at SM-05. Fluctuating moisture conditions were monitored in neutron access tube #5 at this site (Figure 10). Several poorly defined zones of increased moisture content were identified; but significant wetting fronts were uncommon at this site. Downward movement of a wetting front may be indicated by the increased moisture content dropping from the 1.4- to 1.6-ft interval on July 10, to the 1.7- to 1.9- ft interval on July 25 and finally dropping to the 2.0- to 2.1-ft interval on July 30.

Hydrologic processes dominating the moisture balance of the MLS cover includes: surface runoff because of the steeply sloped (19%) surface, infiltration of precipitation, and evapotranspiration by the thin cover of grass.

LOWER COULEE

The Lower Coulee (LC) covers about 12.8 acres (558,400 square feet) below and immediately north of the MLS. This is a relatively gently sloping surface at about .07 ft/ft to the north. Garbage

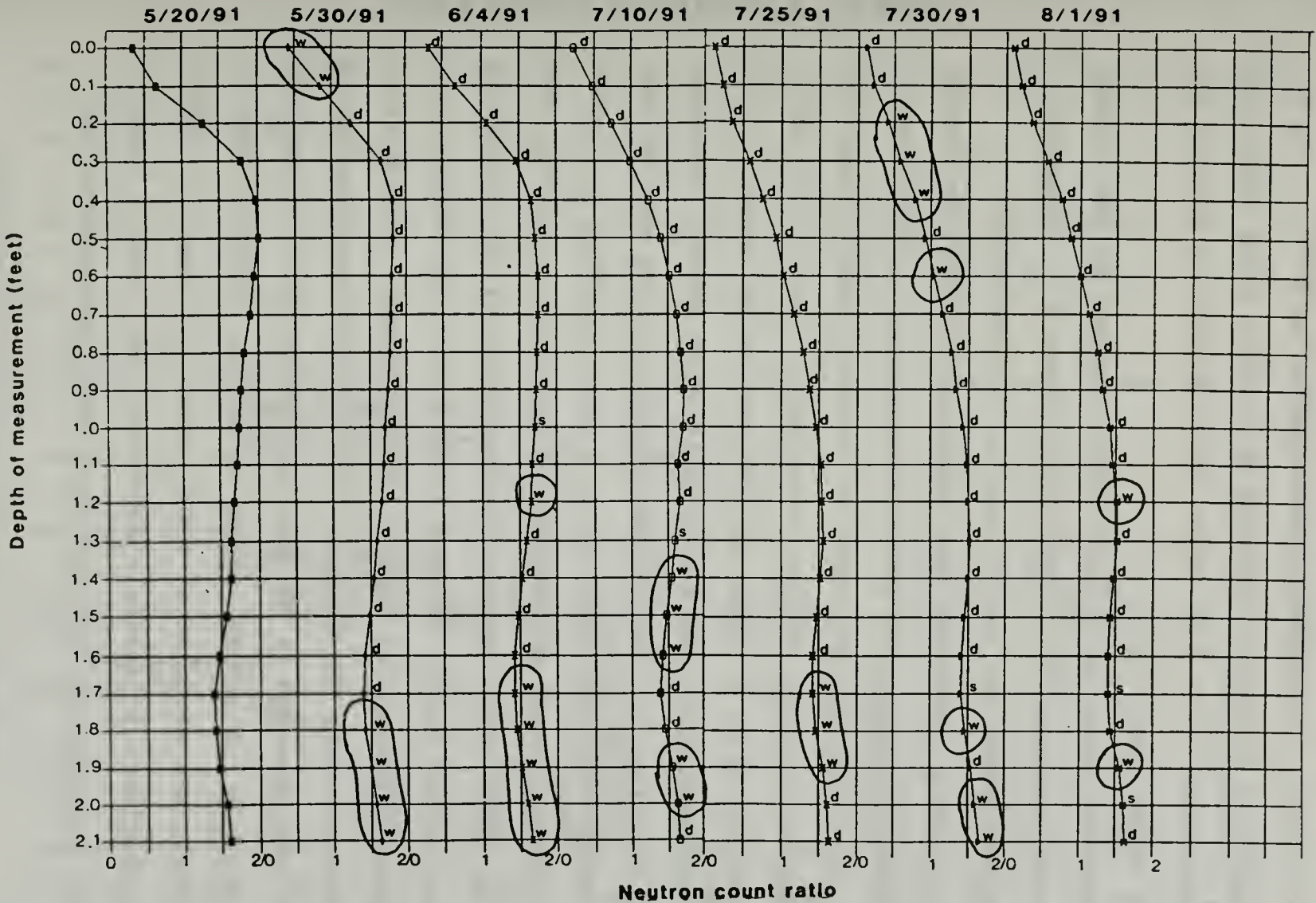


Figure 10. Soil moisture fluctuations at neutron access tube #5 located in the main landfill section of the Billings Landfill at site SM-05. The fluctuations were determined by changes in the neutron count ratio at specific depths through time. A "w" indicates wetter conditions, a "d" indicates drier conditions and an "s" indicates the same moisture conditions as were measured at the same depth interval during the previous measurement.

buried below the LC ranges from 0- to 40-ft thick and averages about 20-ft thick. Soil borings penetrated up to 3-ft of the LC cover. Consisting largely of brownish gray silty sandy clay, the cover ranges from 1- to 3-ft thick. This surface is covered by moderately thick vegetation.

Permeameter tests in the LC cover resulted in Kfs values ranging from 0.00000025 to 0.00015 cm/sec (Table 1). Based on 5 tests the average Kfs for the LC cover is 0.00005 cm/sec.

Soil moisture conditions were monitored at SM-04 in the LC cover. Changes in the matric potential gradients are depicted in Figure 11. The gradients are based on changes in matric potential in the shallow interval between tensiometers T9 (1.0 ft below ground) and T11 (1.58 ft below ground) and in the deep interval between tensiometers T11 and T10 (2.25 ft below ground). Downward gradients prevailed in the shallow interval during most of the year; although one measurement in late July indicated an upward gradient. The magnitude of gradients in the shallow interval also fluctuated; with strong downward gradients during May decreasing steadily up to the upward gradient in late July. The magnitude of descending gradients in the shallow interval showed a similar trend from mid-September to mid-October. Relatively low magnitude upward gradients were measured in the deep tensiometer interval from May until late-July. A strong upward gradient, greater than 10 millibars/cm, was measured in early August; followed by mostly downward gradients of variable magnitude. The overall trend of descending gradients in both intervals after mid-September was

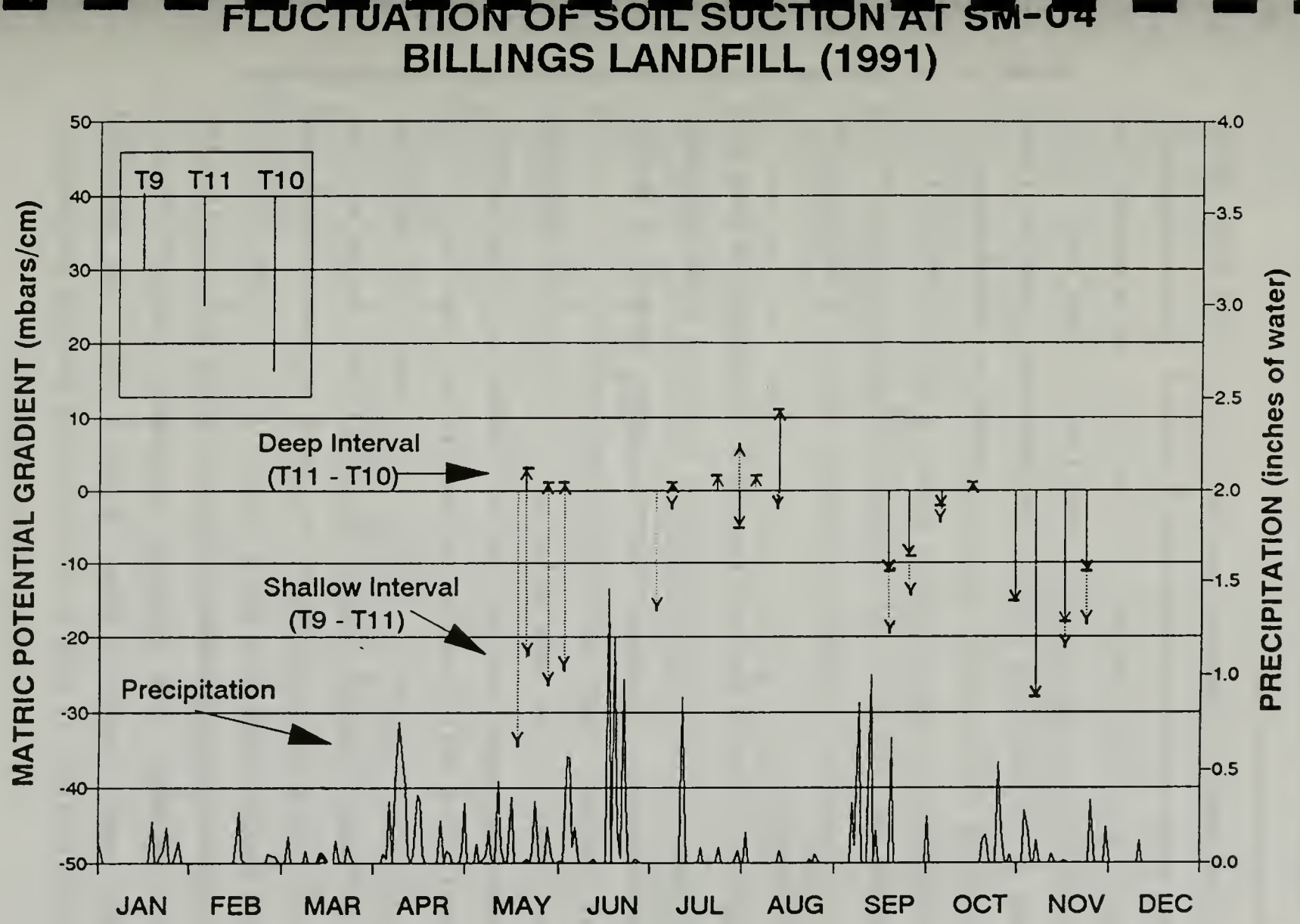


Figure 11. Fluctuations of the matric suction gradients at SM-04 during 1991. Upward gradients are indicated by values greater than zero and downward gradients are indicated by values less than zero. The shallow tensiometer interval is based on soil suction data from T9 set at 1.0 feet below land surface and T11 set at 1.58 feet below land surface. The deep tensiometer interval is based on suction data from T11 set at 1.58 feet below land surface and T10 set at 2.25 feet below land surface.

probably caused by vegetation becoming dormant, resulting in reduced evapotranspiration.

Soil moisture fluctuations were monitored in the LC at SM-04 in neutron access tube #4 (Figure 12). A wetting front is depicted in the May 30 measurement between 0.7- and 1.7-ft below ground. The volume of moisture in the soil decreased from late-May until late-July based on the measuring interval. A remnant of a wetting front probably caused the increased moisture content detected below 1.8 ft on July 25. As in several other sites, a strong wetting front was measured on July 30. The downward movement of this front probably caused the increased moisture content below 0.9 ft measured August 1.

Evapotranspiration and infiltration of precipitation were the dominant hydrologic processes identified in the LC cover. The most significant downward movement of water, based largely on matric potential gradients, occurred after mid-September.

Three monitor wells were installed in colluvium and weathered shale near the north end of the LC (Plate 1). Stratigraphic relationships and well construction details are shown on a cross section through these wells (Figure 13). Weathered shale was penetrated while drilling BL-04 and BL-02; but shale was not encountered while drilling BL-03. Colluvial deposits overlie the shale and contain dark gray silty clay with occasional layers of sand and gravel. Garbage mixed with silty clayey soil overlies the colluvial deposits. The garbage encountered during drilling included: metal, asphalt, glass, plastic, wood, and household wastes. Artificial fill from 2- to 3-ft thick overlies the garbage

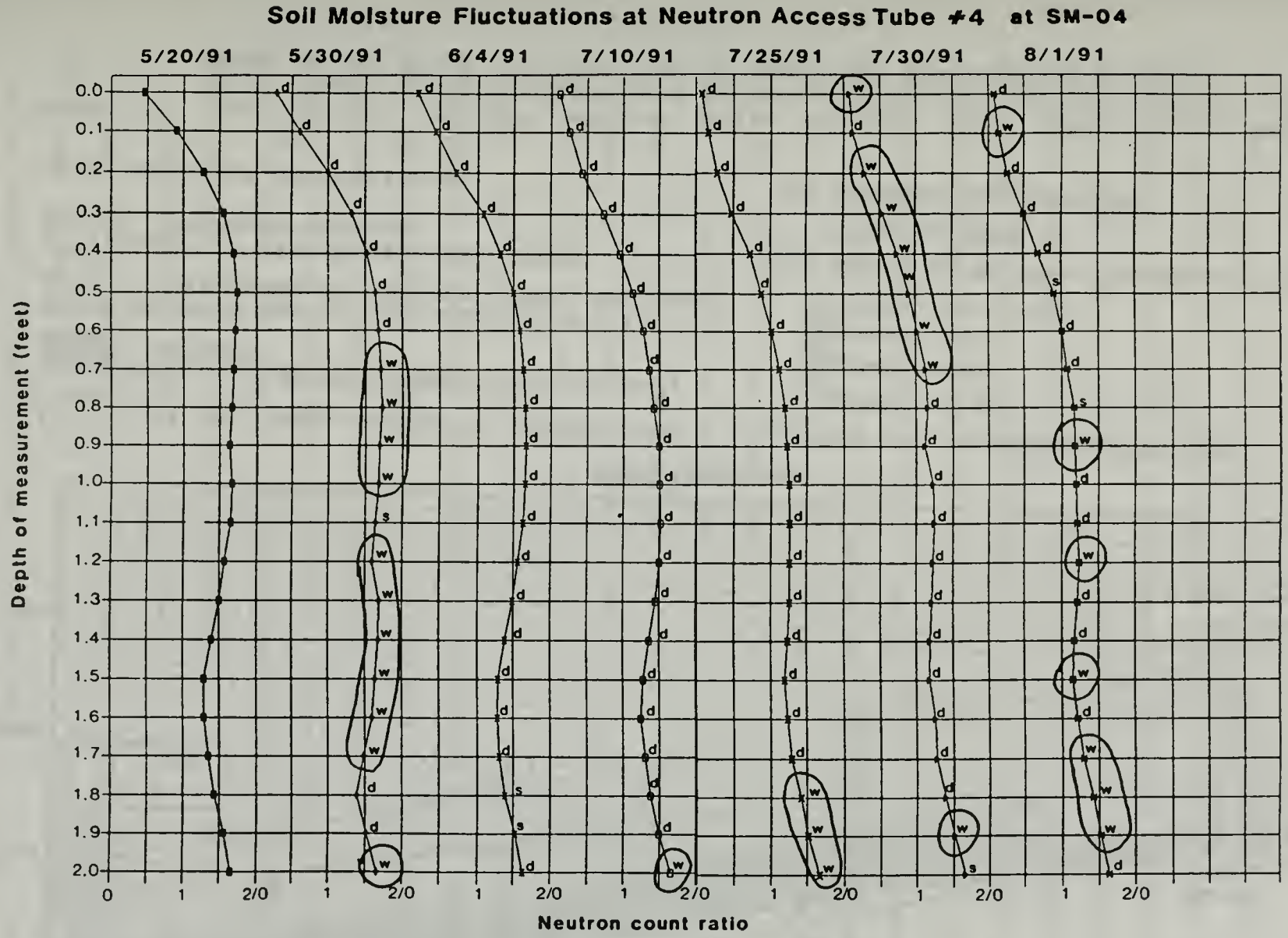


Figure 12. Soil moisture fluctuations at neutron access tube #4 located in the lower coulee section of the Billings Landfill at site SM-04. The fluctuations were determined by changes in the neutron count ratio at specific depths through time. A "w" indicates wetter conditions, a "d" indicates drier conditions and an "s" indicates the same moisture conditions as were measured at the same depth interval during the previous measurement.

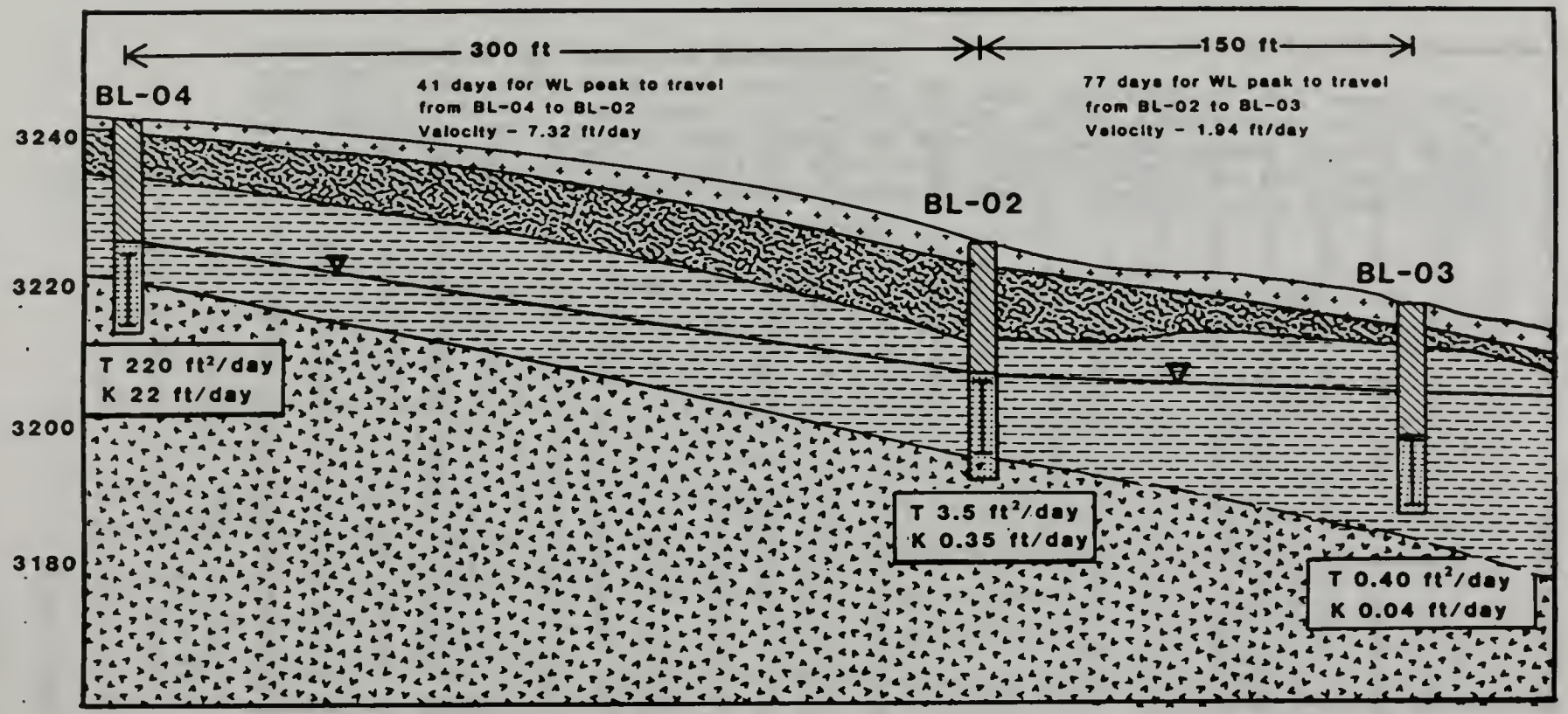


Figure 13. Cross-section through monitor wells showing well construction details, stratigraphic relationships, and hydraulic properties of the colluvial ground water system below the lower coulee section of the Billings Landfill.

layer. The fill consists of a heterogeneous mixture of silt, clay, sand, and gravel.

The saturated zone was monitored using continuous water-level recorders during 1991. Significant differences in both short term and long term water-level fluctuations were observed between the wells (Figures 14, 15, and 16). Short term water-level fluctuations in BL-04 were relatively small (less than 0.1 ft). In contrast, short term water-level fluctuations in BL-02 and BL-03 were much greater (typically more than 1.0 ft). A strong inverse correlation between water-level fluctuations and changes in barometric pressure implied that barometric fluctuations caused the short term rise and fall of the water level in these wells. Barometric responses in wells are common in confined aquifers; and efficiencies of the barometric responses typically range from 20 percent to 75 percent (Freeze and Cherry, 1979). The barometric efficiencies were calculated at 14 percent for BL-04, 70 percent for BL-03, and 78 percent for BL-02. Barometric responses are controlled by the storage coefficient of an aquifer, with high barometric efficiencies indicating low storage coefficients or strongly confined conditions. Based on the high barometric efficiencies of BL-02 and BL-03, ground water tapped by these wells is under strongly confined conditions. In contrast , ground water tapped by BL-04 is under much weaker confined conditions, perhaps either leaky confined or semi-confined conditions.

Long term water-level fluctuations of ground water below the LC appear to be responding to annual fluctuations of recharge and discharge. Water levels in BL-04 rose about 2.3 ft from early May to early August; after which they declined about 1.3 ft by late

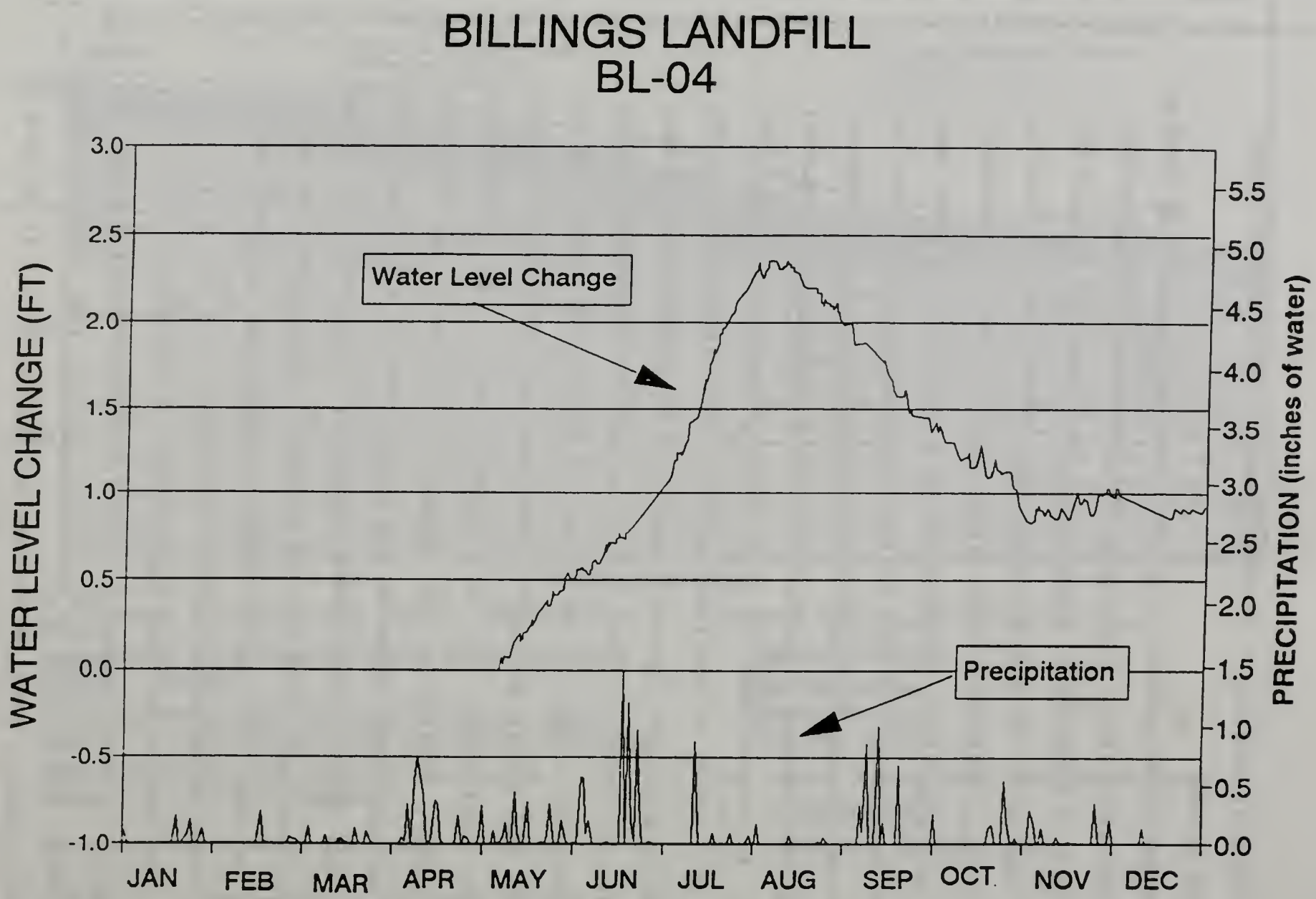


Figure 14. Water levels fluctuated about 2.3 feet at well number BL-04 during 1991. Well BL-04 is screened in colluvial deposits underlying landfilled materials; and is located in the lower coulee section of the Billings landfill.

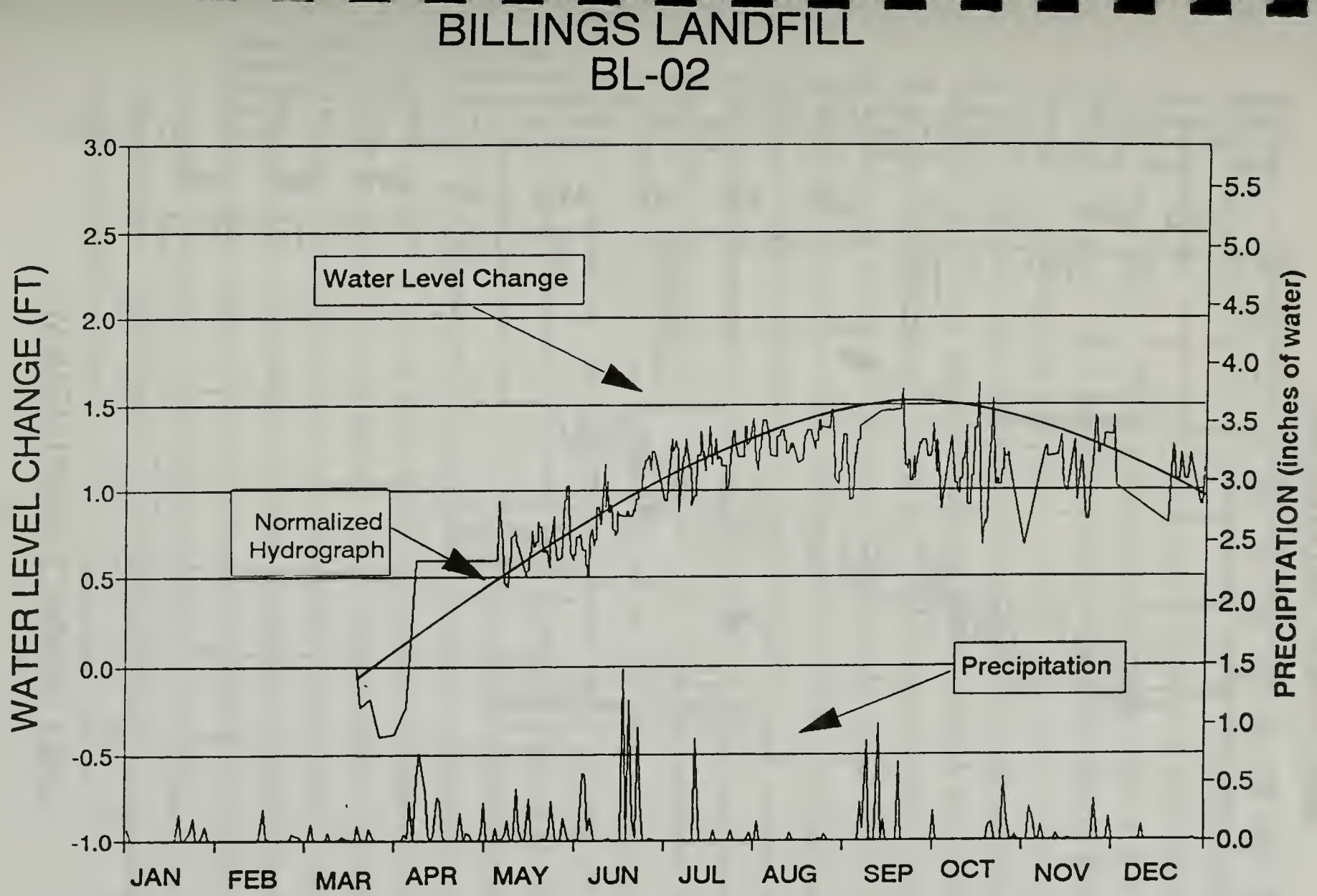


Figure 15. Water levels fluctuated about 1.8 feet at well number BL-02 during 1991. Well BL-02 is screened in colluvial deposits underlying landfilled materials and is located in the lower coulee section of the Billings Landfill. The normalized hydrograph was constructed by visually smoothing the high frequency short-term water-level fluctuations.

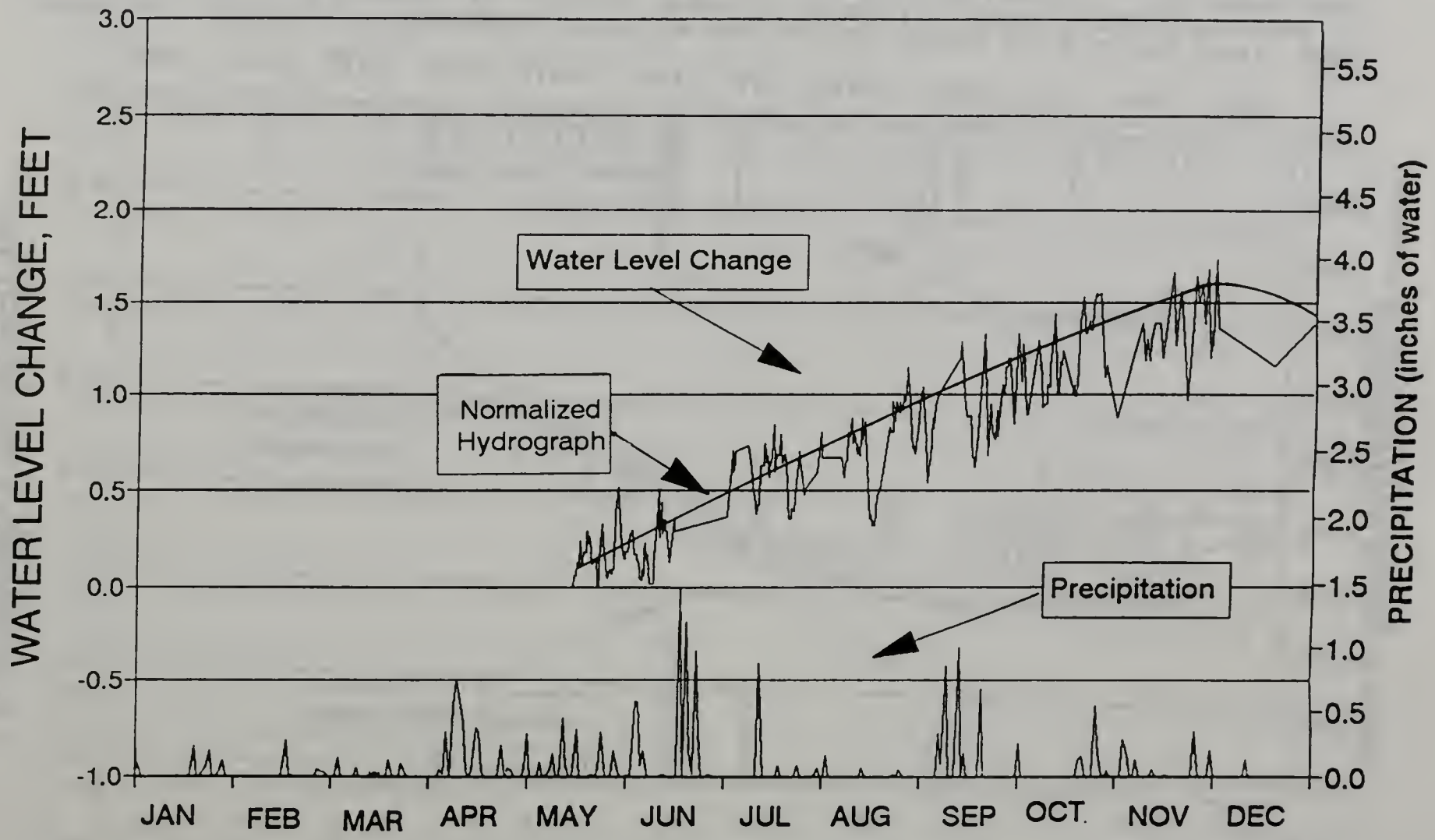


Figure 16. Water levels fluctuated about 1.5 feet at well number BL-03 during 1991. Well BL-02 is screened in colluvial deposits underlying landfilled materials and is located in the lower coulee section of the Billings Landfill. The normalized hydrograph was constructed by visually smoothing the high frequency short-term water-level fluctuations.

October and remained relatively stable throughout the year (Figure 14). Water levels in BL-02 rose about 1.8 ft from early April to mid September; after which they declined about 0.3 ft to the end of 1991 (Figure 15). Water levels in BL-03 rose about 1.5 ft from early May until early December; followed by a decline of about 0.2 ft to the end of 1991 (BL-03).

The long term water level responses can be explained by lateral flow of a pulse of recharge water through the colluvial ground water system. Most of the recharge water probably infiltrated into the colluvial ground-water system near to and upgradient of BL-04; where ground water is under semi-confined or leaky confined conditions. Significantly less precipitation infiltrated vertically into the ground water system in the strongly confined areas near BL-02 and BL-03. As a result, movement of the recharge pulse can be tracked by noting the timing of the peak water level at each well. The peak water level at each well was determined by estimating a normalized hydrograph through the actual hydrograph; accomplished by visually smoothing the high frequency short term water-level fluctuations. Timing of water-level peaks were estimated: at the upgradient well (BL-04) on August 5, at the first downgradient well (BL-02, 300 ft downgradient) on September 15, and at the farthest downgradient well (BL-03, 450 ft downgradient) on December 1. Crude estimates of average effective ground-water velocity can be estimated by dividing the distance ground water would travel between two wells on the same flow path by the number of days between the water-level peak at an upgradient well to the water-level peak at a downgradient well.

The water-level peak at BL-02 was 41 days after the peak at BL-04; resulting in an average ground-water velocity of 7.32 ft/day. The water-level peak at BL-03 was 77 days after the peak at BL-02; resulting in an average ground-water velocity of 1.94 ft/day. Therefore, it appears that effective ground-water velocities decrease down gradient near the north end of the landfill. This decrease is probably caused by fewer and thinner gravel layers in the colluvium towards the north.

The monitor wells were slug tested in June 1992 to determine aquifer characteristics; test results are summarized on Figure 13. The following hydraulic conductivities were calculated: BL-04, 22.0 ft/day; BL-02, 0.35 ft/day; BL-03, 0.04 ft/day. The decline in Kfs towards the north is probably also due to less extensive gravel layers in the colluvium. The reduced hydraulic conductivities supports the previous interpretation that average ground-water velocity decreases towards the north.

## ESTIMATING THE VOLUME OF LEACHATE GENERATION

Soil monitoring gave a qualitative look at the moisture flux into the landfill. The results imply a relatively complicated interaction of hydrologic processes acting on a heterogeneous landfill cover. The timing of moisture flux through the landfill cover varies significantly from one section to another. For example, moisture flux monitoring in the UL indicated the most significant infiltration occurred during July; while moisture flux monitoring in the LC indicated the most significant infiltration after mid-September. Upward moisture flux was also observed in different sections of the landfill; but again the timing of upward

moisture flux was not uniform between the different landfill sections.

Rising water levels in the colluvial ground-water system indicated recharge through the landfill cover. However, the volume, timing, and location of the recharge are not readily apparent. None of these observations provide a quantitative estimate of recharge into the ground-water system or leachate production.

The potential ground-water discharge through the colluvial aquifer system was calculated based on the measured hydraulic conductivity and the observed water-level gradient in the Lower Coulee section of the landfill. Ground-water discharge was evaluated using the Darcy equation:

Q(Ground-water discharge) = K(Hydraulic conductivity) * i (ground-water gradient) * A(average cross-sectional area of the aquifer)

This Darcian analysis was applied to the landfill section between BL-04 and BL-02, because the cross-sectional area is relatively well-defined along this part of the flow path (Figure 13, Plate 1) The following parameters were used: aquifer thickness, 10 ft; aquifer width, 200 ft; ground-water gradient, 22 ft/300 ft. Both high and low hydraulic conductivity values were considered with the high K value set at 22 ft/day based on BL-04 and the low K value set at 0.35 ft/day based on BL-02.

The average ground-water discharge ranged from 51.3 $ft^3$/day to 3227 $ft^3$/day based on the Darcian analysis. Total annual ground water discharge calculated by this method ranges from 18,725 cubic feet to 1,178,000 cubic feet. Most of the ground-water flux through the landfill probably eventually flows through this part of

the colluvial aquifer. Consequently, these discharge values can be compared to discharge values calculated by the HELP model to assess the validity of predicted leachate production.

## HELP MODEL

Leachate production can be estimated by water balance models such as the HELP model (Schroeder and others, 1983). The HELP model requires landfill design factors, climatologic data and soil data to estimate landfill water balance. The model includes default climatologic data for select cities in the U.S.; for example the most similar default climatic data for Billings is from Great Falls. Model results can be optimized by acquiring as much site specific climatic and soil data as possible; for instance, default precipitation data was replaced with actual Billings precipitation data producing more realistic results. Other climatic parameters used in the model appeared less critical; therefore, the default values for Great Falls were retained.

Soil characteristics used in the model were based on measured values of Kfs for each section of the landfill. Keying on this parameter; the field capacity, porosity, wilting point, and evaporation coefficient were interpolated from the default soil characteristics published in the model documentation. Soil characteristics corresponding to the low, high, and average Kfs for each landfill section were evaluated by the HELP model.

Other HELP model input parameters include: design factors relating to the number of layers and surface slope, vegetation density, SCS Runoff curve number, total area of landfill cover, and number of years to be simulated. Steeply sloping sections of the

landfill were given high SCS runoff curve numbers to account for increased surface runoff. Input parameters are listed in Appendix C for each of the landfill sections.

As previously discussed, the Billings Landfill was divided into 5 sections: Upper Landfill, Upper Landfill Slope, Main Landfill, Main Landfill Slope, and Lower Coulee. The Help model was applied to each section resulting in estimates of evapotranspiration, runoff, and percolation from the base of the landfill. Several general assumptions were taken; for example, since the landfill was constructed on top of a thick sequence of low permeability shale, it was assumed that leachate would not infiltrate below the base of the garbage. As a result, any leachate migrating to the base of the garbage would accumulate and eventually drain laterally downgradient on the garbage/shale interface.

The soil characteristics of the garbage layer were assumed to be equal to the default values; which in fact may not be realistic. But, without additional information the default values are the best estimate available. The landfill water balance was simulated for two years, 1990 and 1991. Water-balance totals for each section of the landfill are summarized in Tables 2 to 6, and water-balance totals for the entire landfill are summarized in Tables 7 to 9.

Help model input parameters are based on the average thickness of stratigraphic units , observed density of vegetation, and area of the specific surface. The Upper Landfill consists of a three layer system: 1. a 6-inch thick upper cover layer with moderately thick grass; 2. an 18-inch lower cover layer; and, 3. a 60-ft

thick waste layer. The UL covers about 1,027,000 square ft and slopes to the north at about 3 percent. Soil characteristics of the top layer and the waste layer remained constant for all three simulations. Soil characteristics for the middle layer were based on the range of Kfs values measured from permeameter tests--low Kfs, 0.03259 inches/hour; high Kfs, 0.249 inches/hour; average Kfs, 0.111 inches/hour.

Water balance modelling of the UL predicted between 56,000 and 462,000 cubic ft per year of leachate would be available to percolate from the base of the landfill (Table 2). Significantly more leachate was predicted in 1991 than 1990 in all three scenarios, largely due to the increased precipitation in 1991. Less leachate was predicted by using the average Kfs defaults than the low Kfs defaults. Based on sensitivity analysis this appears to be largely the impact of the default evaporation coefficient on the simulation.

The Upper Landfill Slope is made of two layers; a bare 24-inch thick cover layer and a 80-ft thick lower waste layer. The ULS covers about 478,800 square ft and slopes to the north at about 19 percent. The SCS runoff curve number was set at 95 to account for the slope of the surface. Soil characteristics of the waste layer were held constant for all three simulations; while soil characteristics of the cover layer were based on the range of Kfs values from permeameter tests in the nearby Main Landfill--low Kfs, 0.00279 inches/hour; high Kfs, 0.25364; average Kfs, 0.07885 inches/hour.

Water balance modelling of the ULS predicted between 0 and 116,000 cubic ft per year of leachate was available for percolation

Table 2. Water balance summary for the Upper Landfill

| | LOW kfs | | | AVERAGE kfs | | | HIGH kfs | | |
|---|---|---|---|---|---|---|---|---|---|
| **Annual Totals for 1990** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 11.27 | 964524. | 100.00 | 11.27 | 964524. | 100.00 | 11.27 | 964524. | 100.00 |
| RUNOFF | 0.000 | 0. | 0.00 | 0.000 | 0. | 0.00 | 0.000 | 0. | 0.00 |
| EVAPOTRANSPIRATION | 10.762 | 921078. | 95.50 | 10.900 | 932898. | 96.72 | 10.348 | 885593. | 91.82 |
| PERCOLATION FROM BASE OF LANDFILL | 0.6560 | 56144. | 5.82 | 0.6519 | 55793. | 5.78 | 1.2517 | 107127. | 11.11 |
| **Annual Totals for 1991** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 20.73 | 1774143. | 100.00 | 20.73 | 1774143. | 100.00 | 20.73 | 1774143. | 100.00 |
| RUNOFF | 0.174 | 14877. | 0.84 | 0.173 | 14823. | 0.84 | 0.169 | 14426. | 0.81 |
| EVAPOTRANSPIRATION | 15.614 | 1336284. | 75.32 | 16.435 | 1406600. | 79.28 | 15.119 | 1293944. | 72.93 |
| PERCOLATION FROM BASE OF LANDFILL | 4.9635 | 424791. | 23.94 | 4.1891 | 358517. | 20.21 | 5.3977 | 461954. | 26.04 |
| **Average Annual Totals for 1990 through 1991** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 16.00 | 1369334. | 100.00 | 16.00 | 1369334. | 100.00 | 16.00 | 1369334. | 100.00 |
| RUNOFF | 0.087 | 7439. | 0.54 | 0.087 | 7411. | 0.54 | 0.084 | 7213. | 0.53 |
| EVAPOTRANSPIRATION | 13.188 | 1128681. | 82.43 | 13.668 | 1169749. | 85.42 | 12.733 | 1089769. | 79.58 |
| PERCOLATION FROM BASE OF LANDFILL | 2.8098 | 240468. | 17.56 | 2.4205 | 207155. | 15.13 | 3.3247 | 284541. | 20.78 |

Table 3. Water balance summary for the Upper Landfill Slope

| | LOW kfs | | | AVERAGE kfs | | | HIGH kfs | | |
|---|---|---|---|---|---|---|---|---|---|
| | Annual Totals for 1990 | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 11.27 | 449673. | 100.00 | 11.27 | 449673. | 100.00 | 11.27 | 449673. | 100.00 |
| RUNOFF | 2.414 | 96334. | 21.42 | 0.610 | 24322. | 5.41 | 0.491 | 19596. | 4.36 |
| EVAPOTRANSPIRATION | 8.883 | 354431. | 78.82 | 10.173 | 405890. | 90.26 | 10.037 | 400459. | 89.06 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0174 | 694. | 0.15 | 0.4452 | 17765. | 3.95 | 0.8658 | 34544. | 7.68 |
| | Annual Totals for 1991 | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 20.73 | 827127. | 100.00 | 20.73 | 827127. | 100.00 | 20.73 | 827127. | 100.00 |
| RUNOFF | 8.617 | 343824. | 41.57 | 3.709 | 147996. | 17.89 | 3.213 | 128201. | 15.50 |
| EVAPOTRANSPIRATION | 12.188 | 486283. | 58.79 | 14.020 | 559399. | 67.63 | 14.219 | 567338. | 68.59 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0000 | 0. | 0.00 | 2.7241 | 108692. | 13.14 | 2.9108 | 116143. | 14.04 |
| | Average Annual Totals for 1990 through 1991 | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 16.00 | 638400. | 100.00 | 16.00 | 638400. | 100.00 | 16.00 | 638400. | 100.00 |
| RUNOFF | 5.516 | 220079. | 34.47 | 2.159 | 86159. | 13.50 | 1.852 | 73899. | 11.58 |
| EVAPOTRANSPIRATION | 10.535 | 420357. | 65.85 | 12.096 | 482645. | 75.60 | 12.128 | 483898. | 75.80 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0087 | 347. | 0.05 | 1.5847 | 63229. | 9.90 | 1.8883 | 75344. | 11.80 |

Table 4. Water balance summary for the Main Landfill

| | LOW kfs | | | AVERAGE kfs | | | HIGH kfs | | |
|---|---|---|---|---|---|---|---|---|---|
| **Annual Totals for 1990** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 11.27 | 896153. | 100.00 | 11.27 | 896153. | 100.00 | 11.27 | 896153. | 100.00 |
| RUNOFF | 2.411 | 191675. | 21.39 | 0.000 | 0. | 0.00 | 0.000 | 0. | 0.00 |
| EVAPOTRANSPIRATION | 8.888 | 706715. | 78.86 | 10.674 | 848795. | 94.72 | 10.315 | 820207. | 91.53 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0159 | 1266. | 0.14 | 0.4873 | 38751. | 4.32 | 1.0637 | 84583. | 9.44 |
| **Annual Totals for 1991** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 20.73 | 1648381. | 100.00 | 20.73 | 1648381. | 100.00 | 20.73 | 1648381. | 100.00 |
| RUNOFF | 8.519 | 677423. | 41.10 | 0.472 | 37528. | 2.28 | 0.363 | 28855. | 1.75 |
| EVAPOTRANSPIRATION | 12.300 | 978034. | 59.33 | 15.420 | 1226111. | 74.38 | 15.029 | 1195033. | 72.50 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0000 | 0. | 0.00 | 4.7869 | 380635. | 23.09 | 4.8783 | 387903. | 23.53 |
| **Average Annual Totals for 1990 through 1991** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 16.00 | 1272267. | 100.00 | 16.00 | 1272267. | 100.00 | 16.00 | 1272267. | 100.00 |
| RUNOFF | 5.465 | 434549. | 34.16 | 0.236 | 18764. | 1.47 | 0.181 | 14427. | 1.13 |
| EVAPOTRANSPIRATION | 10.594 | 842375. | 66.21 | 13.047 | 1037453. | 81.54 | 12.672 | 1007620. | 79.20 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0080 | 633. | 0.05 | 2.6371 | 209693. | 16.48 | 2.9710 | 236243. | 18.57 |

Table 5. Water balance summary for the Main Landfill Slope

| | LOW kfs | | | AVERAGE kfs | | | HIGH kfs | | |
|---|---|---|---|---|---|---|---|---|---|
| **Annual Totals for 1990** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 11.27 | 553733. | 100.00 | 11.27 | 553733. | 100.00 | 11.27 | 553733. | 100.00 |
| RUNOFF | 1.921 | 94381. | 17.04 | 0.525 | 25807. | 4.66 | 0.452 | 22202. | 4.01 |
| EVAPOTRANSPIRATION | 9.399 | 461805. | 83.40 | 10.537 | 517694. | 93.49 | 10.190 | 500691. | 90.42 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0005 | 25. | 0.00 | 0.4047 | 19884. | 3.59 | 0.8427 | 41402. | 7.48 |
| **Annual Totals for 1991** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 20.73 | 1018534. | 100.00 | 20.73 | 1018534. | 100.00 | 20.73 | 1018534. | 100.00 |
| RUNOFF | 7.698 | 378246. | 37.14 | 3.368 | 165458. | 16.24 | 2.945 | 144690. | 14.21 |
| EVAPOTRANSPIRATION | 13.167 | 646923. | 63.52 | 15.264 | 749971. | 73.63 | 14.612 | 717927. | 70.49 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0000 | 0. | 0.00 | 1.6505 | 81093. | 7.96 | 2.7724 | 136219. | 13.37 |
| **Average Annual Totals for 1990 through 1991** | | | | | | | | | |
| | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT | (INCHES) | (CU. FT.) | PERCENT |
| PRECIPITATION | 16.00 | 786133. | 100.00 | 16.00 | 786133. | 100.00 | 16.00 | 786133. | 100.00 |
| RUNOFF | 4.810 | 236313. | 30.06 | 1.946 | 95633. | 12.16 | 1.698 | 83446. | 10.61 |
| EVAPOTRANSPIRATION | 11.283 | 554364. | 70.52 | 12.900 | 633832. | 80.63 | 12.401 | 609309. | 77.51 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0003 | 13. | 0.00 | 1.0276 | 50489. | 6.42 | 1.8075 | 88811. | 11.30 |

Table 6. Water balance summary for the Lower Coulee

| | LOW kfs (INCHES) | LOW kfs (CU. FT.) | LOW kfs PERCENT | AVERAGE kfs (INCHES) | AVERAGE kfs (CU. FT.) | AVERAGE kfs PERCENT | HIGH kfs (INCHES) | HIGH kfs (CU. FT.) | HIGH kfs PERCENT |
|---|---|---|---|---|---|---|---|---|---|
| **Annual Totals for 1990** | | | | | | | | | |
| PRECIPITATION | 11.27 | 524431. | 100.00 | 11.27 | 524431. | 100.00 | 11.27 | 524431. | 100.00 |
| RUNOFF | 3.092 | 143879. | 27.44 | 0.000 | 0. | 0.00 | 0.000 | 0. | 0.00 |
| EVAPOTRANSPIRATION | 8.603 | 400334. | 76.34 | 11.624 | 540920. | 103.14 | 11.653 | 542236. | 103.40 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0025 | 117. | 0.02 | 0.0129 | 599. | 0.11 | 0.1460 | 6795. | 1.30 |
| **Annual Totals for 1991** | | | | | | | | | |
| PRECIPITATION | 20.73 | 964636. | 100.00 | 20.73 | 964636. | 100.00 | 20.73 | 964636. | 100.00 |
| RUNOFF | 9.819 | 456903. | 47.37 | 0.547 | 25472. | 2.64 | 0.500 | 23288. | 2.41 |
| EVAPOTRANSPIRATION | 10.906 | 507472. | 52.61 | 18.033 | 839137. | 86.99 | 18.654 | 868050. | 89.99 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0000 | 0. | 0.00 | 1.8243 | 84889. | 8.80 | 1.2948 | 60250. | 6.25 |
| **Average Annual Totals for 1990 through 1991** | | | | | | | | | |
| PRECIPITATION | 16.00 | 744533. | 100.00 | 16.00 | 744533. | 100.00 | 16.00 | 744533. | 100.00 |
| RUNOFF | 6.455 | 300391. | 40.35 | 0.274 | 12736. | 1.71 | 0.250 | 11644. | 1.56 |
| EVAPOTRANSPIRATION | 9.754 | 453903. | 60.96 | 14.829 | 690028. | 92.68 | 15.153 | 705143. | 94.71 |
| PERCOLATION FROM BASE OF LANDFILL | 0.0013 | 59. | 0.01 | 0.9186 | 42744. | 5.74 | 0.7204 | 33523. | 4.50 |

Table 7. Billings Landfill water balance summary--low field saturated hydraulic conductivity (Kfs) main cover layer

| LANDFILL SECTION | PRECIPITATION (cu ft) | RUNOFF (cu ft) | EVAPOTRANSPIRATION (cu ft) | PERCOLATION (cu ft) |
|---|---|---|---|---|
| 1990 | | | | |
| UL | 964,524 | 0 | 921,078 | 56,144 |
| ULS | 449,673 | 96,334 | 354,431 | 694 |
| ML | 896,153 | 191,675 | 706,715 | 1,266 |
| MLS | 553,733 | 94,381 | 461,805 | 25 |
| LC | 524,431 | 143,879 | 400,334 | 117 |
| TOTAL LANDFILL | 3,388,514 | 526,269 | 2,904,363 | 58,246 |
| 1991 | | | | |
| UL | 1,774,143 | 14,877 | 1,336,284 | 424,791 |
| ULS | 827,127 | 343,824 | 486,283 | 0 |
| ML | 1,648,381 | 677,423 | 978,034 | 0 |
| MLS | 1,018,534 | 378,246 | 646,923 | 0 |
| LC | 964,636 | 456,903 | 507,472 | 0 |
| TOTAL LANDFILL | 6,232,821 | 1,871,273 | 3,954,996 | 424,791 |
| AVERAGE | | | | |
| 1990-1991 | | | | |
| UL | 1,369,334 | 7,439 | 1,128,681 | 240,468 |
| ULS | 638,400 | 220,079 | 420,357 | 347 |
| ML | 1,272,267 | 434,549 | 842,375 | 633 |
| MLS | 786,133 | 236,313 | 554,364 | 13 |
| LC | 744,533 | 300,391 | 453,903 | 59 |
| TOTAL LANDFILL | 4,810,667 | 1,198,771 | 3,399,680 | 241,520 |

Table 8. Billings Landfill water balance summary--high field saturated hydraulic conductivity (Kfs) main cover layer

| | LANDFILL SECTION | PRECIPITATION (cu ft) | RUNOFF (cu ft) | EVAPOTRANSPIRATION (cu ft) | PERCOLATION (cu ft) |
|---|---|---|---|---|---|
| 1990 | | | | | |
| | UL | 964,524 | 0 | 885,593 | 107,127 |
| | ULS | 449,673 | 19,596 | 400,459 | 34,544 |
| | ML | 896,153 | 0 | 820,207 | 84,583 |
| | MLS | 553,733 | 22,202 | 500,691 | 41,402 |
| | LC | 524,431 | 0 | 542,236 | 6,795 |
| TOTAL LANDFILL | | 3,388,514 | 41,798 | 3,149,186 | 274,451 |
| 1991 | | | | | |
| | UL | 1,774,143 | 14,426 | 1,293,944 | 461,954 |
| | ULS | 827,127 | 128,201 | 567,338 | 116,143 |
| | ML | 1,648,381 | 28,855 | 1,195,033 | 387,903 |
| | MLS | 1,018,534 | 144,690 | 717,927 | 136,219 |
| | LC | 964,636 | 23,288 | 868,050 | 60,250 |
| TOTAL LANDFILL | | 6,232,821 | 339,460 | 4,642,292 | 1,162,469 |
| AVERAGE | | | | | |
| 1990-1991 | | | | | |
| | UL | 1,369,334 | 7,213 | 1,089,769 | 284,541 |
| | ULS | 638,400 | 73,899 | 483,898 | 75,344 |
| | ML | 1,272,267 | 14,427 | 1,007,620 | 236,243 |
| | MLS | 786,133 | 83,446 | 609,309 | 88,811 |
| | LC | 744,533 | 11,644 | 705,143 | 33,523 |
| TOTAL LANDFILL | | 4,810,667 | 190,629 | 3,895,739 | 718,462 |

Table 9. Billings Landfill water balance summary--average field saturated hyraulic conductivity ($K_{fs}$) main cover layer

| | LANDFILL SECTION | PRECIPITATION (cu ft) | RUNOFF (cu ft) | EVAPOTRANSPIRATION (cu ft) | PERCOLATION (cu ft) |
|---|---|---|---|---|---|
| 1990 | | | | | |
| | UL | 964,524 | 0 | 932,898 | 55,793 |
| | ULS | 449,673 | 24,322 | 405,890 | 17,765 |
| | ML | 896,153 | 0 | 848,795 | 38,751 |
| | MLS | 553,733 | 25,807 | 517,694 | 19,884 |
| | LC | 524,431 | 0 | 540,920 | 599 |
| TOTAL LANDFILL | | 3,388,514 | 50,129 | 3,246,197 | 132,792 |
| 1991 | | | | | |
| | UL | 1,774,143 | 14,823 | 1,406,600 | 358,517 |
| | ULS | 827,127 | 147,996 | 559,399 | 108,692 |
| | ML | 1,648,381 | 37,528 | 1,226,111 | 380,635 |
| | MLS | 1,018,534 | 165,458 | 749,971 | 81,093 |
| | LC | 964,636 | 25,472 | 839,137 | 84,889 |
| TOTAL LANDFILL | | 6,232,821 | 391,277 | 4,781,218 | 1,013,826 |
| AVERAGE | | | | | |
| 1990-1991 | | | | | |
| | UL | 1,369,334 | 7,411 | 1,169,749 | 207,155 |
| | ULS | 638,400 | 86,159 | 482,645 | 63,229 |
| | ML | 1,272,267 | 18,764 | 1,037,453 | 209,693 |
| | MLS | 786,133 | 95,633 | 633,832 | 50,489 |
| | LC | 744,533 | 12,736 | 690,028 | 42,744 |
| TOTAL LANDFILL | | 4,810,667 | 220,703 | 4,013,707 | 573,310 |

from the base of the landfill (Table 3). The impact of more precipitation during 1991 was reflected most in the volume of runoff predicted. In fact, using the low Kfs soil values predicted less percolation in 1991 (a wet year) than 1990 (a dry year).

The Main Landfill consists of a 24-inch thick bare cover layer overlying a 100-ft thick lower waste layer. The ML covers about 954,200 square ft and slopes to the north at about 3 percent. Soil characteristics for the waste layer were held constant for all three simulations. Soil characteristics for the cover layer were based on the range of Kfs measured by permeameter tests in the ML cover--low Kfs, 0.00279 inches/hour; high Kfs,0.25364 inches/hour; average Kfs, 0.07885 inches/hour.

Water balance modelling of the ML predicted between 0 to 388,000 cubic ft of leachate would be available annually to percolate from the base of the ML (Table 4). Again, more leachate was produced during 1991 than 1990 ; except for the low Kfs scenario.

The Main Landfill Slope consists of a 24-inch thick cover layer with thin grass overlying an 80-ft thick lower waste layer. The MLS covers about 589,600 square ft and slopes to the north at about 18 percent. Soil characteristics for the waste layer were held constant for all three simulations. Soil characteristics for the upper soil layer were based on the range of Kfs measured by permeameter tests in the MLS cover--low Kfs, 0.00425 inches/hour; high Kfs, 0.4478 inches/hour; average Kfs, 0.226 inches/hour.

Water balance modelling of the MLS predicted between 0 to 136,219 cubic ft of leachate would be available annually to percolate from the base of the MLS (Table 5) . The runoff

percentage portion of the water balance was similar to what was predicted in the ULS, another steep sloped section of the landfill. More leachate was typically produced during 1991 than 1990 ; except for the low Kfs scenario.

The Lower Coulee consists of a 24-inch thick bare cover layer covered with moderately thick grass overlying a 20-ft thick lower waste layer. The LC covers about 558,400 square ft and slopes to the north at about 7 percent. Soil characteristics for the waste layer were held constant for all three simulations. Soil characteristics for the upper soil layer were based on the range of Kfs measured by permeameter tests in the LC cover--low Kfs, 0.00035 inches/hour; high Kfs, 0.2126 inches/hour; average Kfs, 0.0778 inches/hour.

Water balance modelling of the LC predicted between 0 to 85,000 cubic ft of leachate would be available annually to percolate from the base of the LC (Table 6) . Anomalous relationships were apparent in the volumes predicted including: more leachate predicted in 1990 than in 1991 for the low Kfs scenario, and more leachate predicted by the average Kfs than the high Kfs soil defaults in 1991.

The total landfill water balance is summarized in Tables 7, 8, and 9; relating to soil characteristics based on low Kfs, high Kfs, and average Kfs respectively. The apparently anomalous water balance predictions identified in the individual landfill sections are normal when all parts of the landfill are combined. The water balance summary for the low Kfs indicates evapotranspiration is the largest influence on the water balance in both wet and dry years (Table 7). The potential for evapotranspiration is great enough

that much of the increased precipitation is removed before infiltrating into the landfill cover. Runoff is the next largest influence on the water balance in both wet and dry years, ranging from 9 times the percolation volume during a dry year to 4.4 times the percolation during a wet year.

Evapotranspiration has the greatest influence on the water balance during both wet and dry years based on the high Kfs soil characteristics (Table 8). But, in this case, percolation has the next greatest influence on the water balance in both wet and dry years, ranging from 6.6 times the runoff volume during a dry year to 3.4 times the runoff volume during a wet year.

The water balance based on average Kfs soil characteristics computed intermediate volumes of water percolating from the base of the landfill (Table 9). The HELP model simulation based on the low Kfs soil defaults predicted 58,246 cubic feet of potential leachate in 1990 and 424,791 cubic feet of potential leachate in 1991. The average leachate predicted for these two years based on the low Kfs soil defaults was 241,520 cubic feet per year.

The HELP model simulation based on the high Kfs soil defaults predicted 274,451 cubic feet of potential leachate in 1990 and 1,162,469 cubic feet of potential leachate in 1991. The average leachate predicted for these two years based on the low Kfs soil defaults was 718,462 cubic feet per year.

The HELP model simulation based on the average Kfs soil defaults predicted 132,792 cubic feet of potential leachate in 1990 and 1,013,826 cubic feet of potential leachate in 1991. The average leachate predicted for these two years based on the low Kfs soil defaults was 573,310 cubic feet per year.

The leachate volume predicted by the HELP model fits within the range of potential ground-water discharge (18,725-1,178,000 cubic feet/year) calculated to flow through the colluvial ground-water system draining the landfill.

SWIM MODEL

The SWIM model is another water balance model that can be used to calculate moisture flux through unsaturated soils. It is more generic than the HELP model which was designed specifically for landfill applications. The two models rely on different types of input on default parameters. As a result it is difficult to directly compare the water balance calculated from one model with the other. For example, runoff is calculated by the SWIM model by inputting soil storage factors, a precipitation constant, a runoff rate factor, and a runoff power variable; while the HELP model uses the SCS runoff number. Similar discrepancies between the two models are also apparent for calculating soil characteristics, vegetation impacts, and evaporation impacts. Consequently, a direct comparison of the two models was not attempted.

The SWIM model was tested to simulate observed soil moisture fluctuations monitored at the landfill. It was assumed that modelling may help indicate which set of soil characteristics used in the HELP model produce the most realistic leachate volumes. Preliminary testing of the SWIM model using data from the UL indicated that the low Kfs defaults will predict roughly similar matric potentials that were measured at SM-01 during the summer of 1991. In contrast, the model predicted unrealistic matric potentials when the average or high field saturated conductivities were used as the default soil characteristics. The vegetative

cover on the UL complicated the analyses but it was unclear how the vegetative cover impacted the model results. Consequently, a more detailed analysis of the bare ML cover was conducted using the SWIM model.

Moisture flux through the ML was simulated by the SWIM model for 100 days during the summer of 1991; coinciding with the period of most intense field monitoring. The model started on May 20 and ended on August 27. Initial moisture conditions were based on the observed matric potentials at SM-03 and soil characteristics estimated from the low, high, and average field saturated hydraulic conductivities of the ML cover. Precipitation was simulated for the 100 day period based on observed accumulations at the Billings airport. Evaporation amounts were summed from the HELP model output over the 100 day period. The vegetation type was set to simulate bare ground. Soil hydraulic properties were the only parameters adjusted during the SWIM simulations; these are summarized in Table 10.

The results of the SWIM simulation are summarized in Tables 11, 12 and 13; representing soil hydraulic properties relating to low, average, and high Kfs and their associated default values. None of the simulations closely predicted the measured matric potentials at SM-03. The simulation based on the low Kfs defaults most closely approached the measured matric potentials; with most predicted values within one order of magnitude of the observed values. The predicted potentials were generally larger (less negative) than the observed potentials. Using the average and high Kfs defaults, matric potentials were predicted that were more than one order of magnitude smaller than most observed matric

TABLE 10. Soil characteristics input into SWIM simulation of the Main Landfill

| Depth cm | PSIE (clay defaults) | b (clay defaults) | Matric Potential measured 5/20 at SM-03 | Low kfs Defaults Water Content/kfs (0.93 * Porosity)/cm/hr | Average kfs Defaults Water Content/kfs (0.93 * Porosity)/cm/hr | High kfs Defaults WaterContent/kfs (0.93 * Porosity)/cm/hr |
|---|---|---|---|---|---|---|
| 0 | -50 | 25 | -120 | .502/.0079 | .454/.20028 | .481/.64425 |
| 10 | -50 | 25 | -120 | .502/.0079 | .454/.20028 | .481/.64425 |
| 25 | -50 | 25 | -120 | .502/.0079 | .454/.20028 | .481/.64425 |
| 30 | -50 | 25 | -120 | .502/.0079 | .454/.20028 | .481/.64425 |
| 31 | -50 | 25 | -769 | .502/.0079 | .454/.20028 | .481/.64425 |
| 43 | -50 | 25 | -769 | .502/.0079 | .454/.20028 | .481/.64425 |
| 50 | -50 | 25 | -769 | .502/.0079 | .454/.20028 | .481/.64425 |
| 51 | -50 | 25 | -745 | .502/.0079 | .454/.20028 | .481/.64425 |
| 60 | -50 | 25 | -745 | .502/.0079 | .454/.20028 | .481/.64425 |
| 70 | -50 | 25 | -745 | .502/.0079 | .454/.20028 | .481/.64425 |
| 74 | -50 | 25 | -745 | .502/.0079 | .454/.20028 | .481/.64425 |
| 80 | -50 | 25 | -745 | .502/.0079 | .454/.20028 | .481/.64425 |
| Cumulative Evaporation for 100 day period | | | | 104.7 mm | 146.8 mm | 145.6 mm |

Table 11. Comparison of measured matric potential at site SM-03 with matric potential simulated by the SWIM model for low kfs defaults

| Depth (cm) | Initial Matric Potential 5-20 (cm) | Matric Potential Predicted/Measured 5-29/5-30 (cm) | Matric Potential Predicted/Measured 6-08/6-04 (cm) | Matric Potential Predicted/Measured 7-08/7-10 (cm) | Matric Potential Predicted/Measured 7-18/7-25 (cm) | Matric Potential Predicted/Measured 7-28/7-30 (cm) | Matric Potential Predicted/Measured 8-07/8-01 (cm) |
|---|---|---|---|---|---|---|---|
| 0 | -120 | -380 | -10 | -401 | -130 | -484 | -1100 |
| 10 | -120 | -253 | -10 | -213 | -100 | -257 | -400 |
| 25 | -120 | -250/-286 | -27/-265 | -144/-243 | -84/-258 | -183/-272 | -276/-258 |
| 30 | -120 | -263 | -34 | -132 | -80 | -169 | -255 |
| 31 | -769 | -268 | -35 | -130 | -80 | -167 | -251 |
| 43 | -769 | -342/-784 | -53/-795 | -113/-774 | -76/-738 | -147/-712 | -221/-691 |
| 50 | -769 | -405 | -67 | -106 | -75 | -139 | -208 |
| 51 | -745 | -415 | -68 | -106 | -75 | -138 | -207 |
| 60 | -745 | -509 | -94 | -100 | -74 | -131 | -196 |
| 70 | -745 | -594 | -136 | -96 | -74 | -127 | -189 |
| 74 | -745 | -616/-740 | -153/-761 | -95/-803 | -74/-777 | -126/-755 | -188/-740 |
| 80 | -745 | -628 | -165 | -95 | -74 | -125 | -187 |

Table 12. Comparison of measured matric potential at site SM-03 with matric potential simulated by the SWIM model for average kfs defaults

| Depth (cm) | Initial Matric Potential 5-20 (cm) | Matric Potential Predicted/Measured 5-29/5-30 (cm) | Matric Potential Predicted/Measured 6-08/6-04 (cm) | Matric Potential Predicted/Measured 7-08/7-10 (cm) | Matric Potential Predicted/Measured 7-18/7-25 (cm) | Matric Potential Predicted/Measured 7-28/7-30 (cm) | Matric Potential Predicted/Measured 8-07/8-01 (cm) |
|---|---|---|---|---|---|---|---|
| 0 | -120 | -812 | -182 | -2012 | -945 | -3922 | -22,600 |
| 10 | -120 | -731 | -183 | -1506 | -818 | -2430 | -5873 |
| 25 | -120 | -654/-286 | -183/-265 | -1172/-243 | -709/-258 | -1782/-272 | -3548/-258 |
| 30 | -120 | -636 | -183 | -1105 | -685 | -1668 | -3232 |
| 31 | -769 | -632 | -183 | -1094 | -681 | -1649 | -3181 |
| 43 | -769 | -601/-784 | -183/-795 | -988/-774 | -640/-738 | -1479/-712 | -2758/-691 |
| 50 | -769 | -589 | -183 | -947 | -623 | -1415 | -2607 |
| 51 | -745 | -587 | -183 | -942 | -621 | -1408 | -2589 |
| 60 | -745 | -576 | -183 | -907 | -607 | -1354 | -2466 |
| 70 | -745 | -569 | -183 | -885 | -598 | -1320 | -2389 |
| 74 | -745 | -567/-740 | -183/-803 | -880/-761 | -596/-777 | -1313/-755 | -2373/-740 |
| 80 | -745 | -566 | -183 | -877 | -594 | -1309 | -2364 |

Table 13. Comparison of measured matric potential at site SM-03 with matric potential simulated by the SWIM model for high kfs defaults

| Depth (cm) | Initial Matric Potential 5-20 (cm) | Matric Potential Predicted/Measured 5-29/5-30 (cm) | Matric Potential Predicted/Measured 6-08/6-04 (cm) | Matric Potential Predicted/Measured 7-08/7-10 (cm) | Matric Potential Predicted/Measured 7-18/7-25 (cm) | Matric Potential Predicted/Measured 7-28/7-30 (cm) | Matric Potential Predicted/Measured 8-07/8-01 (cm) |
|---|---|---|---|---|---|---|---|
| 0 | -120 | -934 | -308 | -2320 | -1326 | -3969 | -12,583 |
| 10 | -120 | -892 | -308 | -2054 | -1237 | -3261 | -7485 |
| 25 | -120 | -845/-286 | -308/-265 | -1808/-243 | -1138/-258 | -2747/-272 | -5464/-258 |
| 30 | -120 | -832 | -308 | -1750 | -1114 | -2640 | -5131 |
| 31 | -769 | -830 | -308 | -1740 | -1109 | -2621 | -5075 |
| 43 | -769 | -807/-784 | -308/-795 | -1639/-774 | -1062/-738 | -2450/-712 | -4608/-691 |
| 50 | -769 | -796 | -307 | -1598 | -1048 | -2382 | -4439 |
| 51 | -745 | -795 | -307 | -1592 | -1046 | -2374 | -4420 |
| 60 | -745 | -786 | -307 | -1556 | -1029 | -2316 | -4284 |
| 70 | -745 | -779 | -307 | -1531 | -1018 | -2279 | -4200 |
| 74 | -745 | -778/-740 | -307/-761 | -1526/-803 | -1016/-777 | -2271/-755 | -4183/-740 |
| 80 | -745 | -777 | -307 | -/1524 | -1014 | -2267 | -4173 |

potentials. The SWIM simulation indicates that defaults based on the low Kfs best predicts the existing matric potentials at SM-03. Assuming the conditions at SM-03 are representative of the Main Landfill, leachate volumes based on the low Kfs defaults are probably the most realistic.

## CONCLUSIONS

The Billings Landfill is a dynamic hydrologic system composed of many lifts of waste containing interbedded layers of relatively low permeability clay and relatively high permeability garbage. A final clay cover has not yet been established ; but temporary to semi-permanent clay layers are continually emplaced to reduce leachate production. The combined lifts of waste are over 200-ft thick in the Main Landfill. In addition to the heterogeneous stratigraphy, the vegetative cover, surface slope, and topography of the landfill are very diverse. Because of this diversity the landfill was divided into the following 5 sections for hydrologic evaluation: Upper Landfill, Upper Landfill Slope, Main Landfill, Main Landfill Slope, and Lower Coulee. The temporary and semi-permanent cover layers are the only layers readily accessible for field testing and monitoring. As a result, many of the variables required to accurately model moisture flux have been estimated.

The leachate production potential of the Billings Landfill was evaluated first by assessing the soil characteristics of the landfill; and then by using interpretations based on these observations to simulate the water balance using the HELP model. Another computer model, the SWIM model tested the range of soil

moisture characteristics; indicating the most reasonable set of parameters for estimating leachate production.

Soil monitoring in the landfill cover included: permeameter tests, estimating Kfs; periodic neutron probe measurements, identifying changes in water content; and periodic tensiometer measurements, identifying both the magnitude and direction of matric potential gradients.

Soil monitoring provided a qualitative estimate of moisture flux through the landfill cover. The results imply a relatively complicated interaction of hydrologic processes acting on a heterogeneous landfill cover. The timing and volume of moisture flux through the landfill cover varies significantly, both between landfill sections and within individual landfill sections. Water is infiltrating through the landfill cover, potentially producing leachate; and water is also evaporating and/or transpiring out of the landfill, removing potential leachate. Data was insufficient to directly compute the landfill water balance; but the fact that ground-water levels below the Lower Coulee rose significantly during 1991 implies that precipitation falling on the drainage basin containing the landfill recharges the underlying ground-water system. Consequently, water infiltrates through waste and forms leachate. Leachate movement is impeded in the colluvial ground-water system by decreasing hydraulic conductivities reducing the average ground-water velocity towards the boundary of the landfill. Steady state flow is maintained through this segment of the colluvial aquifer because as the ground-water velocity decreases the thickness of the colluvial aquifer increases.

The HELP simulation of the entire landfill predicted leachate

volumes ranging from 58,246 cubic feet per year to 1,162,469 cubic feet per year depending on the climatic conditions and the soil characteristics used to describe the landfill cover. Leachate volumes were estimated to range between 58,246 cubic feet to 274,451 cubic feet for the drier than average year (1990); while leachate volumes were estimated to range between 424,791 cubic feet to 1,162,469 cubic feet for the wetter than average year (1991). Since default soil characteristic values were used for the waste layer in the HELP model, the computed volumes could be significantly different than the actual leachate produced; with the most likely impact being a reduction in leachate due to the many clay layers included in the waste layer. The leachate volumes predicted by HELP fall within the range of calculated discharge flowing below the Lower Coulee section of the landfill (18,725-1,178,000 cubic feet/year). Consequently, regardless of the use of assumptions and defaults in the HELP model reasonable leachate volumes appear to have been predicted.

The SWIM model simulation that best described the observed matric potentials in the Main Landfill was based on low Kfs soil values. Therefore, assuming the particular site (SM-03) is representative of the Main Landfill section; leachate production based on the low Kfs soil values is probably the most realistic. Similarly, based on preliminary evaluation of the vegetated Upper Landfill section, the low Kfs soil defaults appear best and therefore are probably the most representative of the entire landfill. Consequently, the Billings Landfill probably produced

about 58,000 cubic feet and 425,000 cubic feet of leachate in 1990 and 1991 respectively.

Although results of the SWIM model and the HELP model could not be directly compared, these models did complement each other. The SWIM model was used to test the default soil characteristics used in the HELP model. By comparing SWIM simulated soil moisture fluctuations with observed soil moisture fluctuations, it was found that soil characteristics based on low Kfs values produced roughly similar matric potentials. In contrast, unrealistic matric potentials were predicted by the SWIM model when default soil characteristics were based on high or average Kfs values.

Accurately predicting the volume of leachate produced by the Billings Landfill would require soil testing and moisture flux monitoring far beyond the scope of this project. Heterogeneity of the landfill stratigraphic units including the interbedded garbage and clay of the waste layer and the cover material would require more boreholes, field testing, soil moisture analyses, and soil moisture monitoring. More accurate monitoring of climatic conditions would undoubtedly improve the accuracy of a calculated water balance. The evapotranspiration effects of vegetation is another parameter that would require much more accurate calculation. Water quality monitoring would provide additional information that would help define leachate movement. Much of this monitoring would need to be continued for several years; with additional sampling sites established when landfill operations destroy other sampling sites. Since it is very costly and difficult to collect all the data required to adequately assess the volume of leachate produced in a landfill; the HELP model is a

valuable predictive tool. The accuracy of predictions can be significantly improved by over-riding as many of the defaults as possible with site specific field measurements. Testing the accuracy of the predictions would require comparing modelling results with actual volumes of leachate collected and actual volumes of runoff measured.

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# APPENDIX A

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Yellowstone Location: T. 1 S R. 26 E Sec. 29 Tract: BACC01 Hole name or Number BL-01

Hole location: Drilled along west side of main landfill access road NE of 2nd gravel pile, located about 500 feet in from gate.

Recorded by: JR Date hole Started: 03/15/91 Date hole Completed: 03/15/91 Driller: F. Schmidt Drilling Company MBMG

Total Well depth (ft) 33 Well diameter: 5" Casing diameter(s) and length (s): No casing Surface Elevation: 3225

Type of casing(s): Weight or gage of casing: Method-perforated or screened:

Interval-perforated or screened: None

Has or will well be test pumped?: Were material samples taken?: Was a water sample taken?:

Remarks: No well

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

| From | To | |
|---|---|---|
| 0 | 3 | Dark gray, silty clay with pebbles and cobbles, fill |
| 3 | 10 | Very dark gray, silty clay with pebbles, cobbles, metal and lumber, fill |
| 10 | 22 | Very dark gray, silty clay with a few pebbles, colluvium |
| 22 | 25 | Black clay with yellow streaks, weathered shale |
| 25 | 30 | Gray clay |
| 30 | 33 | Gray clay, harder drilling, shale |
| | | Hole bridged @ 13' |
| | | Reamed to 25' and backfilled with clay cuttings |

# APPENDIX A (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Yellowstone Location: T. 1 S R. 26 E Sec. 29 Tract: BBDAD1 Hole name or Number BL-02

Hole location: Drilled in center of main coulee, 150 feet nw of BL-01, located about 500 feet in from main gate.

Recorded by: JR Date hole Started: 04/08/91 Date hole Completed: 04/08/91 Driller: F. Schmidt Drilling Company MBMG

Total Well depth (ft) 29 Well diameter: 5" hole 2" well Casing diameter(s) and length (s): 2" - 20' Surface Elevation: 3225

Type of casing(s): Plastic Weight or gage of casing: Schedule 200 Method-perforated or screened:

Interval-perforated or screened: 19-29 with 2-inch #20 slot in PVC screen; gravel packed 17-33

Has or will well be test pumped?: Were material samples taken?: Was a water sample taken?:

Remarks: Drilled in middle of coulee -- abandoned first attempt (cuttings & shale), moved back 2 feet and redrilled.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

| From | To | |
|---|---|---|
| 0 | 4 | Grayish brown, slightly clayey, very fine sandy, silt with small flat shale pebbles; fill |
| 4 | 13 | Grayish brown, slightly clayey, very fine sandy, silt with large cobbles, metal and wood, garbage |
| 13 | 18 | No returns, easy drilling, abandoned, hole too crooked, colluvium, backfilled with bentonite chips, moved up and redrilled |
| 0 | 2 | Grayish brown, slightly clayey, very fine sandy, silt with small flat shale pebbles; fill |
| 2 | 13 | Grayish brown, slightly clayey, very fine sandy, silt with large cobbles, metal and wood, garbage |
| 13 | 33 | Dark gray silty clay, water bearing zones, possibly weathered shale at about 30'; colluvium/shale |
| | | Installed 2-inch well<br>20' 2" PVC 10' #20 slot screen<br>1 foot out of ground, SI = 19-29, gravel packed to about 17', poured 1 bag bentonite crumbles on top of gravel pack. Grouted with very heavy mud from top of bentonite seal (13') to land surface. |

# APPENDIX A (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Yellowstone Location: T. 1 S R. 26 E Sec. 29 Tract: BBDA02 Hole name or Number BL-03

Hole location: Billings landfill west of entrance road next to first gravel pile, located about 200 feet from main gate.

Recorded by: JR Date hole Started: 04/08/91 Date hole Completed: 04/08/91 Driller: F. Schmidt Drilling Company MBMG

Total Well depth (ft) 29 Well diameter: 2" in a 5" hole Casing diameter(s) and length (s): 2" - 20' Surface Elevation: 3217

Type of casing(s): Weight or gage of casing: Schedule 200 Method-perforated or screened:

Interval-perforated or screened: SI = 19-29

Has or Will well be test pumped?: Were material samples taken?: Was a water sample taken?:

Remarks: Gravel, cobbles and clay on surface edge of berm used to contain flood waters in gully

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

| From | To | |
|---|---|---|
| 0 | 3 | Grayish brown, silty, clayey, coarse gravel, fill |
| 3 | 5 | Metal, wood with clay, few returns, garbage |
| 5 | 30 | Olive gray, silty clay, soft |

No returns until about 20'; hole is about 10" in diameter; clay contains scattered pebbles and significant amounts of sand; wet at about 23-25'; colluvium

Installed 2" well (overdrilled to 30')
20' of blank 10' of #20 slot screen
1' out of ground
SI = 19-29
Gravel packed to 19' poured 1 bag of bentonite chips and left open for grouting
Grouted with very heavy mud from top of bentonite
Seal (15') to land surface

# APPENDIX A (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Yellowstone Location: T. 1 S R. 26 E Sec. 29 Tract: BBDD01 Hole name or Number BL-04

Hole location: Lower part of Billings landfill west of road next to 2nd gravel pile.

Recorded by: JR Date hole Started: 04/08/91 Date hole Completed: 04/08/91 Driller: F. Schmidt Drilling Company MBMG

Total Well depth (ft) 29 Well diameter: 5" hole 2"well Casing diameter(s) and length (s): 2" - 20' Surface Elevation: 3244

Type of casing(s): Plastic Weight or gage of casing: Schedule 200 Method-perforated or screened:

Interval-perforated or screened: 19' - 29' with 2 inch #20 slot PVC screen

Has or will well be test pumped?: No Were material samples taken?: No Was a water sample taken?: No

Remarks: Clay and gravel on land surface east edge of gully.

---

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

| From | To | |
|---|---|---|
| 0 | 2 | Grayish brown, gravelly, silty sand, clay |
| 2 | 4 | Plastic, wood, and gravel, garbage |
| 4 | 8 | Black, tarry, sand and gravel, asphalt |
| 8 | 24 | Grayish brown, silty, sandy clay, wet thin sand and gravel layers, harder drilling about 23', possible shale, colluvium/shale |
| 24 | 30 | Moderately hard dark gray and yellowish brown, shale, angular large cuttings, fairly easy drilling, weathered shale |
| | | Installed 2" well, 20' of PVC 10' screen (#20 slot) 1' out of ground; gravel packed to 16'; poured 1 bag of bentonite crumbles on top of gravel pack; left open for grouting. Grouted with very heavy mud from top of bentonite seal approximately 12' to land surface. |

# APPENDIX B

## LOGS OF SOIL BORINGS

GP-01 3/20/91

Lower Coulee

0 - 5" Very moist, dark brown, gray, silty clay with pebbles, wood fragments and plastic

5 - 8" Damp to dry, brownish-gray, silty clay, with pebbles, hand auger would not penetrate past 8".

GP-02 3/25/91

Lower Coulee

0 - 9" Moist, dark brown, silty, clayey, pebbly, medium- to coarse-sand

GP-03 3/25/91

Lower Coulee

0 - 2" Moist, light-grayish-brown, silty clay, thick root mat

2 - 10" Damp, light-grayish-brown, silty clay, a few pebbles

GP-04 3/25/91

Lower Coulee

0 - 4" Damp, light-grayish-brown, silty clay

4 - 8" Dry, light-grayish-brown, silty clay

8 - 16" Dry, pale brown, silty, clay

16 - 19" Dry, pale brown, silty, clay, $CACO_3$ flecks, iron oxide staining, glass at 18" along with plastic and other garbage

GP-05 3/28/91

Lower Coulee

0 - 10" Damp, light-grayish-brown, silty clay, with white streaks of carbonate or sulfate salts.

10 - 18" Dry, grayish-brown, silty, sandy, clay with white streaks of carbonate or sulfate salts

GP-06 3/28/91

Main Landfill Slope

0 - 2" Moist, light-grayish-brown, silty clay

2 - 4" Damp, light-grayish-brown, silty clay

4 - 10" Dry, light-grayish-brown, silty clay, and clayey silt

10 - 18" Dry, light-grayish-brown, silty clay, plastic and other garbage at 15"

GP-07 3/28/91

Main Landfill Slope

0 - 4" Moist, grayish-brown, silty clay

4 - 10" Dry, light-grayish-brown, very clayey silt, with pebbles of shale

GP-08 4/1/91

Main Landfill Slope

0 - 2" Damp, grayish-brown, silty clay

2 - 4" Moist, light-grayish-brown, silty clay

4 - 6" Damp, light-grayish-brown, silty clay

6 - 11" Dry, light-grayish-brown, sandy, silty clay

11 - 15" light-grayish-brown, sandy clay, with plastic, wood, pebbles, etc., could not penetrate past 15"

GP-09 4/1/91

Upper Landfill

0 - 7" Dry, very dark brown, clayey silt, soft organic-rich layer

7 - 12" Damp, medium-gray, silty clay

12 - 20" Clay with plastic, glass, wood and paper

GP-10 4/1/91

Upper Landfill

0 - 7" Dry, very dark brown, clayey silt, soft, organic-rich layer

7 - 15" Damp, light-yellowish-brown, sandy, clayey silt, with light gray streaks, hard layers of pale brown, clayey silt

GP-11 4/1/91

Upper Landfill

0 - 3" Dry, dark brown, clayey silt, soft, organic-rich layer

3 - 10" pale brown, clayey silt, with hard layers

GP-12 4/2/91

Upper Landfill

0 - 3" Dry, dark brown, clayey silt, soft, organic-rich layer

3 - 15" Dry, pale brown, clayey silt

15 - 20" pale brown, silty clay with plastic, paper and wood fragments

GP-13 4/2/91

Upper Landfill

0 - 4" Dry, dark brown, clayey silt, soft, organic-rich layer

4 - 10" Damp, light-yellowish-brown, silty, clay

10 - 12" Damp, pale brown, silty clay

12 - 18" Damp, pale brown, silty clay, with paper, glass, and other garbage

GP-14 4/2/91

0 - 1" Dry, brownish-gray, clayey, silt

1 - 14" Damp, light-yellowish-brown, clayey silt, with plastic

14 - 19" Dry, very dark gray, silty shale, hard

GP-15 4/5/91

Main Landfill

0 - 7" Damp, light-grayish-brown, silty clay

GP-16 4/5/91

Main Landfill

0 - 5" Dry, yellowish-brown, silty clay

5 - 10" Damp, light-grayish-brown, silty clay, with garbage

GP-17 4/6/91

Main Landfill

0 - 9" Damp, light-grayish-brown, silty clay

GP-18 4/6/91

Main Landfill

0 - 12" Damp, light-grayish-brown, silty clay with bentonitic streaks

12 - 15" Damp, light-grayish-brown, silty clay, with garbage, could not penetrate past 15"

GP-19 4/6/91

Main Landfill

0 - 3" Dry, pale brown, silty clay

3 - 9" Damp, light-yellowish-brown, silty clay

9 - 18" Damp, light-grayish-brown, silty clay, with very dark gray shale pebbles

GP-20 4/6/91

Main Landfill

0 - 8" Dark, grayish-brown, silty clay, with dark gray shale pebbles

8 - 10" Damp, dark-grayish-brown, silty clay, with garbage

GP-21

Upper Landfill

0 - 4" Dry, dark-grayish-brown, clayey silt, soft, organic-rich layer

4 - 8" Damp, Dark grayish-brown, clayey silt

8 - 20" Damp, yellowish-brown, silty clay, with angular shale pebbles and rounded igneous pebbles, could not penetrate past 20 inches

SM-01

Upper Landfill

N-01 4/9/91

0 - 6" Dry, dark brown loam, soft, organic-rich layer

6 - 12" Damp, brownish gray, silt, clay with white salt streaks

12 - 18" Damp, gray, silty clay

18 - 24" Clay with garbage

T-1 set at 16"
T-2 set at 11"
T-3 set at 6"

SM-02

Upper Landfill

N-02

0 - 5" Dry, brownish-gray loam, soft, organic-rich layer

5 - 15" Damp, medium-gray, silty clay

15 - 19" Clay with garbage

T-4 set at 12"
T-5 set at 7"

SM-03

Main Landfill

N-03 4/9/91

0 - 6" Dry, light-grayish-brown, silty clay, with shale

6 - 12" Damp, grayish-brown, silty clay, with garbage

12 - 24" Damp, grayish-brown, silty clay

24 - 30" Damp, very dark gray, silty clay, with shale

30 - 36" Garbage

T-6 set at 29"
T-7 set at 17"
T-8 set at 10"

SM-04

Lower Coulee

N-04

0 - 18" Damp, brownish-gray, silty clay

18 - 24" Damp, brownish-gray, silty clay, with white carbonate fragments

24 - 27" Clay with garbage, mostly wood chips and glass

T-9 set at 12"
T-10 set at 27"
T-11 set at 19"

SM-05

Main Landfill Slope

N-05

0 - 4" Moist, grayish-brown, silty clay

4 - 10" Dry, grayish-brown, silty clay

10 - 22" Dry, grayish-brown, silty clay, with carbonate salts

22 - 29" Silty clay, with garbage

APPENDIX C

## HELP MODEL INPUT PARAMETERS
## UPPER LANDFILL (LOW)

**DESIGN FACTOR:** THREE LAYERS; SURFACE SLOPE 3%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO LOW FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 6.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.3660 VOL/VOL |
| FIELD CAPACITY | = | 0.2000 VOL/VOL |
| WILTING POINT | = | 0.1210 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 9.03999805 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 18.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.800 MM/DAY**0.5 |
| POROSITY | = | 0.5920 VOL/VOL |
| FIELD CAPACITY | = | 0.5010 VOL/VOL |
| WILTING POINT | = | 0.3780 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.03259000 INCHES/HR |

LAYER 3

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 720.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 1027000. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.337 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 4.5640 INCHES |
| INITIAL VEG. STORAGE | = | 2.7210 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |

| | |
|---|---|
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## UPPER LANDFILL (AVERAGE)

**DESIGN FACTOR:** THREE LAYERS; SURFACE SLOPE 3%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO AVERAGE FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

| | | |
|---|---|---|
| **LAYER 1** | | |
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 6.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.3660 VOL/VOL |
| FIELD CAPACITY | = | 0.2000 VOL/VOL |
| WILTING POINT | = | 0.1210 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 9.03999805 INCHES/HR |
| **LAYER 2** | | |
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 18.00 INCHES |
| EVAPORATION COEFFICIENT | = | 5.000 MM/DAY**0.5 |
| POROSITY | = | 0.5350 VOL/VOL |
| FIELD CAPACITY | = | 0.4210 VOL/VOL |
| WILTING POINT | = | 0.2220 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.11100000 INCHES/HR |
| **LAYER 3** | | |
| WASTE LAYER | | |
| THICKNESS | = | 720.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 1027000. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.424 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 4.3360 INCHES |
| INITIAL VEG. STORAGE | = | 2.2490 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |

| | |
|---|---|
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

**HELP MODEL INPUT PARAMETERS**
**UPPER LANDFILL (HIGH)**

**DESIGN FACTOR:** THREE LAYERS; SURFACE SLOPE 3%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO HIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 6.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.3660 VOL/VOL |
| FIELD CAPACITY | = | 0.2000 VOL/VOL |
| WILTING POINT | = | 0.1210 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 9.03999901 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 18.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.800 MM/DAY**0.5 |
| POROSITY | = | 0.5180 VOL/VOL |
| FIELD CAPACITY | = | 0.3530 VOL/VOL |
| WILTING POINT | = | 0.2090 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.24890001 INCHES/HR |

LAYER 3

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 720.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

**GENERAL SIMULATION DATA**

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 1027000. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.410 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 4.2680 INCHES |
| INITIAL VEG. STORAGE | = | 2.0870 INCHES |

**CLIMATIC VARIABLES**
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |

| | |
|---|---|
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## UPPER LANDFILL SLOPE (LOW)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 18%

**VEGETATION:** BARE GROUND

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO LOW FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

| | | LAYER 1 |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.150 MM/DAY**0.5 |
| POROSITY | = | 0.5400 VOL/VOL |
| FIELD CAPACITY | = | 0.4700 VOL/VOL |
| WILTING POINT | = | 0.3780 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.00279000 INCHES/HR |

| | | LAYER 2 |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 960.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 95.00 |
| TOTAL AREA OF COVER | = | 478800. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 4.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.150 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 2.1600 INCHES |
| INITIAL VEG. STORAGE | = | 1.6960 INCHES |

### CLIMATIC VARIABLE
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 0.00 |
| 162 | 0.00 |
| 176 | 0.00 |
| 189 | 0.00 |
| 203 | 0.00 |
| 216 | 0.00 |
| 230 | 0.00 |
| 243 | 0.00 |
| 257 | 0.00 |
| 270 | 0.00 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

HELP MODEL INPUT PARAMETERS
UPPER LANDFILL SLOPE (AVERAGE)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 18%

**VEGETATION:** BARE GROUND

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO AVERAGE FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.480 MM/DAY**0.5 |
| POROSITY | = | 0.4880 VOL/VOL |
| FIELD CAPACITY | = | 0.3550 VOL/VOL |
| WILTING POINT | = | 0.2340 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.07885000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 960.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

**GENERAL SIMULATION DATA**

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 95.00 |
| TOTAL AREA OF COVER | = | 478800. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 4.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.480 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 1.9520 INCHES |
| INITIAL VEG. STORAGE | = | 1.1780 INCHES |

**CLIMATIC VARIABLES**
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 0.00 |
| 162 | 0.00 |
| 176 | 0.00 |
| 189 | 0.00 |
| 203 | 0.00 |
| 216 | 0.00 |
| 230 | 0.00 |
| 243 | 0.00 |
| 257 | 0.00 |
| 270 | 0.00 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

HELP MODEL INPUT PARAMETERS
UPPER LANDFILL SLOPE (HIGH)

DESIGN FACTORS: TWO LAYERS; SURFACE SLOPE 18%

VEGETATION: BARE GROUND

SOIL CHARACTERISTICS: BASED ON DEFAULT VALUES CORRESPONDING TO HIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.680 MM/DAY**0.5 |
| POROSITY | = | 0.5170 VOL/VOL |
| FIELD CAPACITY | = | 0.3490 VOL/VOL |
| WILTING POINT | = | 0.2080 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.25364000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 960.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 95.00 |
| TOTAL AREA OF COVER | = | 478800. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 4.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.680 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 2.0680 INCHES |
| INITIAL VEG. STORAGE | = | 1.1140 INCHES |

CLIMATIC VARIABLE
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 0.00 |
| 162 | 0.00 |
| 176 | 0.00 |
| 189 | 0.00 |
| 203 | 0.00 |
| 216 | 0.00 |
| 230 | 0.00 |
| 243 | 0.00 |
| 257 | 0.00 |
| 270 | 0.00 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

HELP MODEL INPUT PARAMETERS
MAIN LANDFILL (LOW)

DESIGN FACTORS: TWO LAYERS; SURFACE SLOPE 3%

VEGETATION: BARE GROUND

SOIL CHARACTERISTICS: BASED ON DEFAULT VALUES CORRESPONDING TO TO LOW FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.150 MM/DAY**0.5 |
| POROSITY | = | 0.5400 VOL/VOL |
| FIELD CAPACITY | = | 0.4700 VOL/VOL |
| WILTING POINT | = | 0.3780 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.00279000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 1200.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 954200. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 4.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.150 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 2.1600 INCHES |
| INITIAL VEG. STORAGE | = | 1.6960 INCHES |

CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 0.00 |
| 162 | 0.00 |
| 176 | 0.00 |
| 189 | 0.00 |
| 203 | 0.00 |
| 216 | 0.00 |
| 230 | 0.00 |
| 243 | 0.00 |
| 257 | 0.00 |
| 270 | 0.00 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## MAIN LANDFILL (AVERAGE)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 3%

**VEGETATION:** BARE GROUND

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO AVERAGE FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.480 MM/DAY**0.5 |
| POROSITY | = | 0.4880 VOL/VOL |
| FIELD CAPACITY | = | 0.3550 VOL/VOL |
| WILTING POINT | = | 0.2340 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.07885000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 1200.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 954200. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 4.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.480 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 1.9520 INCHES |
| INITIAL VEG. STORAGE | = | 1.1780 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
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| 149 | 0.00 |
| 162 | 0.00 |
| 176 | 0.00 |
| 189 | 0.00 |
| 203 | 0.00 |
| 216 | 0.00 |
| 230 | 0.00 |
| 243 | 0.00 |
| 257 | 0.00 |
| 270 | 0.00 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## MAIN LANDFILL (HIGH)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 3%

**VEGETATION:** BARE GROUND

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO HIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.680 MM/DAY**0.5 |
| POROSITY | = | 0.5170 VOL/VOL |
| FIELD CAPACITY | = | 0.3490 VOL/VOL |
| WILTING POINT | = | 0.2080 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.25364000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 1200.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 954200. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 4.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.680 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 2.0680 INCHES |
| INITIAL VEG. STORAGE | = | 1.1140 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

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| 162 | 0.00 |
| 176 | 0.00 |
| 189 | 0.00 |
| 203 | 0.00 |
| 216 | 0.00 |
| 230 | 0.00 |
| 243 | 0.00 |
| 257 | 0.00 |
| 270 | 0.00 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## MAIN LANDFILL SLOPE (LOW)

DESIGN FACTORS: TWO LAYERS; SURFACE SLOPE 3%

VEGETATION: POOR GRASS

SOIL CHARACTERISTICS: BASED ON DEFAULT VALUES CORRESPONDING TO TO LOW FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.200 MM/DAY**0.5 |
| POROSITY | = | 0.5500 VOL/VOL |
| FIELD CAPACITY | = | 0.4800 VOL/VOL |
| WILTING POINT | = | 0.3840 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.00425000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 960.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 95.00 |
| TOTAL AREA OF COVER | = | 589600. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 6.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.200 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 3.3000 INCHES |
| INITIAL VEG. STORAGE | = | 2.5920 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

HELP MODEL INPUT PARAMETERS
MAIN LANDFILL SLOPE (AVERAGE)

DESIGN FACTORS: TWO LAYERS; SURFACE SLOPE 3%

VEGETATION: POOR GRASS

SOIL CHARACTERISTICS: BASED ON DEFAULT VALUES CORRESPONDING TO TO AVERAGE FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.570 MM/DAY**0.5 |
| POROSITY | = | 0.5140 VOL/VOL |
| FIELD CAPACITY | = | 0.3670 VOL/VOL |
| WILTING POINT | = | 0.2170 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.22602998 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 960.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 95.00 |
| TOTAL AREA OF COVER | = | 589600. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 6.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.570 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 3.0840 INCHES |
| INITIAL VEG. STORAGE | = | 1.7520 INCHES |

CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

**HELP MODEL INPUT PARAMETERS**
**MAIN LANDFILL SLOPE (NIGH)**

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 3%

**VEGETATION:** POOR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO NIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.750 MM/DAY**0.5 |
| POROSITY | = | 0.4850 VOL/VOL |
| FIELD CAPACITY | = | 0.2630 VOL/VOL |
| WILTING POINT | = | 0.1390 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.44780001 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 960.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

**GENERAL SIMULATION DATA**

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 95.00 |
| TOTAL AREA OF COVER | = | 589600. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 6.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.750 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 2.9100 INCHES |
| INITIAL VEG. STORAGE | = | 1.2060 INCHES |

**CLIMATIC VARIABLES**
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
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| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

HELP MODEL INPUT PARAMETERS
LOWER COULEE (LOW)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 7%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO LOW FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.160 MM/DAY**0.5 |
| POROSITY | = | 0.5450 VOL/VOL |
| FIELD CAPACITY | = | 0.4740 VOL/VOL |
| WILTING POINT | = | 0.3800 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.00035000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 240.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

**GENERAL SIMULATION DATA**

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 558400. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 3.160 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 5.4500 INCHES |
| INITIAL VEG. STORAGE | = | 4.2700 INCHES |

**CLIMATIC VARIABLES**
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
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| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## LOWER COULEE (AVERAGE)

DESIGN FACTORS: TWO LAYERS; SURFACE SLOPE 7%

VEGETATION: FAIR GRASS

SOIL CHARACTERISTICS: BASED ON DEFAULT VALUES CORRESPONDING TO TO AVERAGE FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.400 MM/DAY**0.5 |
| POROSITY | = | 0.4950 VOL/VOL |
| FIELD CAPACITY | = | 0.3620 VOL/VOL |
| WILTING POINT | = | 0.2410 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.07780000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 240.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 558400. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.400 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 4.9500 INCHES |
| INITIAL VEG. STORAGE | = | 3.0150 INCHES |

CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
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| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## LOWER COULEE (HIGH)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 7%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO HIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.500 MM/DAY**0.5 |
| POROSITY | = | 0.5210 VOL/VOL |
| FIELD CAPACITY | = | 0.3750 VOL/VOL |
| WILTING POINT | = | 0.2200 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.21255000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 240.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

**GENERAL SIMULATION DATA**

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 558400. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.500 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 5.2100 INCHES |
| INITIAL VEG. STORAGE | = | 2.9750 INCHES |

**CLIMATIC VARIABLES**
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
|---|---|
| 1 | 0.00 |
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| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

## HELP MODEL INPUT PARAMETERS
## LOWER COULEE (HIGH)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 7%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO HIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.500 MM/DAY**0.5 |
| POROSITY | = | 0.5210 VOL/VOL |
| FIELD CAPACITY | = | 0.3750 VOL/VOL |
| WILTING POINT | = | 0.2200 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.21255000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 240.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 558400. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.500 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 5.2100 INCHES |
| INITIAL VEG. STORAGE | = | 2.9750 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 136.88 | 212.89 | 329.90 | 456.57 | 558.94 | 609.59 |
| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

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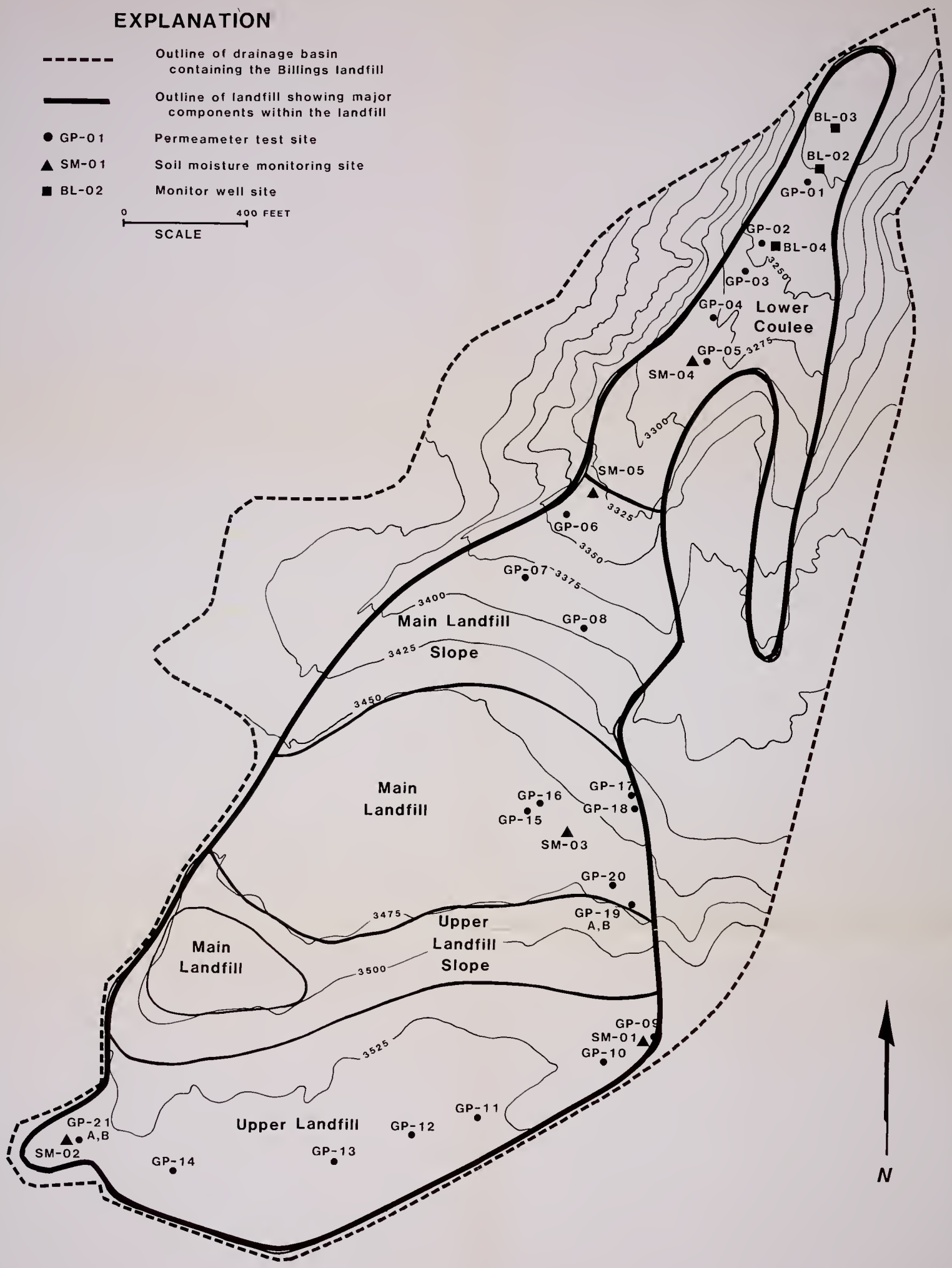
| 1 | 0.00 |
| 135 | 0.00 |
| 149 | 1.84 |
| 162 | 3.00 |
| 176 | 3.00 |
| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)

# PLATE 1 - BILLINGS LANDFILL



## HELP MODEL INPUT PARAMETERS
## LOWER COULEE (HIGH)

**DESIGN FACTORS:** TWO LAYERS; SURFACE SLOPE 7%

**VEGETATION:** FAIR GRASS

**SOIL CHARACTERISTICS:** BASED ON DEFAULT VALUES CORRESPONDING TO TO HIGH FIELD SATURATED HYDRAULIC CONDUCTIVITIES FOR LAYER 1

LAYER 1

| | | |
|---|---|---|
| VERTICAL PERCOLATION LAYER | | |
| THICKNESS | = | 24.00 INCHES |
| EVAPORATION COEFFICIENT | = | 4.500 MM/DAY**0.5 |
| POROSITY | = | 0.5210 VOL/VOL |
| FIELD CAPACITY | = | 0.3750 VOL/VOL |
| WILTING POINT | = | 0.2200 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.21255000 INCHES/HR |

LAYER 2

| | | |
|---|---|---|
| WASTE LAYER | | |
| THICKNESS | = | 240.00 INCHES |
| EVAPORATION COEFFICIENT | = | 3.300 MM/DAY**0.5 |
| POROSITY | = | 0.5200 VOL/VOL |
| FIELD CAPACITY | = | 0.3200 VOL/VOL |
| WILTING POINT | = | 0.1900 VOL/VOL |
| EFFECTIVE HYDRAULIC CONDUCTIVITY | = | 0.28299999 INCHES/HR |

### GENERAL SIMULATION DATA

| | | |
|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 85.00 |
| TOTAL AREA OF COVER | = | 558400. SQ. FT |
| EVAPORATIVE ZONE DEPTH | = | 10.00 INCHES |
| EFFECTIVE EVAPORATION COEFFICIENT | = | 4.500 MM/DAY**0.5 |
| UPPER LIMIT VEG. STORAGE | = | 5.2100 INCHES |
| INITIAL VEG. STORAGE | = | 2.9750 INCHES |

### CLIMATIC VARIABLES
(default values for Great Falls)

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.11 | 23.90 | 31.30 | 42.35 | 54.07 | 63.33 |
| 67.64 | 65.85 | 58.45 | 47.40 | 35.68 | 26.42 |

MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
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| 594.95 | 518.94 | 401.93 | 275.27 | 172.90 | 122.24 |

LEAF AREA INDEX TABLE

| DATE | LAI |
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| 189 | 3.00 |
| 203 | 3.00 |
| 216 | 3.00 |
| 230 | 2.70 |
| 243 | 1.96 |
| 257 | 0.96 |
| 270 | 0.50 |
| 366 | 0.00 |

PRECIPITATION BASED ON DAILY MEASUREMENTS FROM BILLINGS (SEE FIG. 2)